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TECHNICAL REPORT 3632

**EVALUATION
OF
52100 HYPEREUTECTOID STEEL
FOR THE
M151 2.75 - INCH ROCKET WARHEAD (U)**

STANLEY WAXMAN

OCTOBER 1967

**PICATINNY ARSENAL
DOVER, NEW JERSEY**

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EVALUATION
OF
52100 HYPEREUTECTOID STEEL
FOR THE
M151 2.75-INCH ROCKET WARHEAD (U)

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OCTOBER 1967

AMMUNITION ENGINEERING DIRECTORATE
PICATINNY ARSENAL
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(U) SUMMARY

Hypereutectoid Type AISI E52100 steel was evaluated by the Ammunition Engineering Directorate's Ammunition Engineering Laboratory for its suitability as an alternate material for the two-piece pearlitic malleable iron (PMI) M151 Warhead of the 2.75-Inch Rocket System.

The 52100 steel was applicable for one-piece fabrication -- to produce the desired fragmentation. Other segments were investigating 52100 steel using a novel and expensive heat treatment to produce a carbide network to obtain optimum fragmentation. However, this process was not considered practical for the 2.75-inch warhead because of the large production requirement. The intention was to utilize conventional furnace and temper techniques to obtain fragmentation equivalent to the PMI Warhead.

One hundred warheads produced by Chamberlain Corporation of Waterloo, Iowa, were subjected to a series of engineering design tests for this investigation. The material proved acceptable. A follow-up pilot production of these warheads was undertaken to confirm suitability of this steel and to develop a manufacturing process for these warheads. However, as a result of the mass production process developed by Chamberlain Corporation, acceptable fragmentation could only be attained with a material too brittle to pass minimum safety requirements. A drop test was used to evaluate the suitability of these warheads for excessive brittleness, and the drop test results were later confirmed by actual charpy impact tests. An investigation was made to determine the cause of brittleness in the production samples.

Attempts to modify the heat treatment to satisfy requirements as well as provide good fragmentation were not successful.

(U) CONCLUSIONS

For the steel warheads to achieve comparable fragmentation with PMI rounds, a hardness requirement of RC 52-58 was established. However, this requirement did not apply to the nose and base areas which had to be soft for threading.

This hardness requirement was achieved by the contractor during the initial production of 100 warheads by furnace heating and oil quench and tempering, followed by induction softening of the nose and base ends. This process resulted in warheads which passed all safety and performance tests. During the follow-up pilot production phase, the most economical process developed to meet these requirements utilized a vertical induction scanning unit which selectively hardened the major center area, leaving the ends soft. This process produced warheads too brittle to pass minimum safety requirements. An investigation revealed the presence of banding in these warheads and traced this condition back to the production starting slug. This banding condition (which essentially acts as brittle stringers) was not present in the early test samples, according to the investigation.

Attempts to modify heat treatment to satisfy both safety drop and fragmentation requirements failed.

(U) STUDY

Hypereutectoid steel was initially investigated as an alternate material to PMI to broaden the supply base of the M151 Warhead for the 2.75-Inch Rocket.

This warhead is presently fabricated from a two-piece design with the nose section produced as a casting from PMI (FMI and Ductile iron can also be used) and silver-brazed to a cupped base which can either be cast from PMI or cold formed from low carbon steel. The Army anticipated that future procurement for this item would be increased substantially and therefore the one-piece hypereutectoid steel warhead (Figure 1) could expand supply channels in the metal working industry to meet the Army's increased production requirements.

The M151 Warhead is a fragmentation warhead developed for the 2.75-Inch XM3 Rocket Launcher in conjunction with the helicopter armament program. It is loaded with 2.3 lbs. of Composition B4 explosive. The base section has an Acme thread for attachment to the front end of the Mk 40 rocket motor. The nose end of the warhead is threaded to accommodate the M423 Point Detonating (PD) Rocket Fuze (or XM427E1 Fuze for Air Force application).

History

The 2.75-Inch Rocket was originally developed by the Navy primarily for air-to-air service and utilized a six-lb. forged steel warhead. In applying this rocket for its air-to-ground application, the Army initiated an R&D program to redesign the warhead to increase lethality (Figure 2). In this connection, a 10-lb. warhead (produced from PMI as a two-piece design with a brazed joint) was developed and safety certified in October 1964 (as the XM151). In June 1964, Chamberlain Corporation sent Picatinny Arsenal four warheads reflecting the Navy's six-lb. warhead design and the Army's 10-lb. PMI design. However, these warheads were machined from E52100 steel bar stock to meet the dimensional requirements and were heat-treated at 1,550°F for one hour, oil quenched and stress relieved for one hour at 700°F. Fragmentation tests conducted at Picatinny Arsenal revealed that Chamberlain Corporation's (E52100 steel) six-lb. warhead was appreciably superior to the Navy's six-lb. warhead and the Chamberlain's 10-lb. steel warhead was comparable to Picatinny Arsenal's 10-lb. PMI warhead.

During June 1965, Chamberlain Corporation submitted an unsolicited proposal to develop a warm-forged cold-drawn hypereutectoid steel body for the XM151 Warhead. The firm estimated that the warhead -- as developed by Chamberlain Corporation -- could be mass-produced for \$4.98 each where these assumptions were made:

1. Production quantity -- 400,000 per year.
2. Material -- E52100 steel produced in the open hearth for 12 cents per lb. plus freight.
3. Heat Treatment -- conventional, furnace soak, oil quench and temper.
4. Facilities -- conventional furnaces, presses and machine tools such as would be widely available in industry.
5. Completion of a successful engineering program to develop the process.
6. Design -- one piece with elimination of the brazed joint. This design must be acceptable to the Government.

Chamberlain Corporation then sent Picatinny Arsenal fragmentation data for 52100 steel utilizing test cylinders designed to evaluate the 2.75-Inch Rocket Warhead charge to mass (C/M) ratio parameters. These cylinders had previously been heat-treated to various hardness levels and therefore the data of percent by weight vs. weight group (grams) revealed the extensive work which had been accomplished by Chamberlain Corporation -- both through company-sponsored as well as Air Force and Navy contracts (Table 1).

Initial Test Phase

Picatinny Arsenal negotiated Contract DA-28-017-AMC-2230 (A), April 1965, with Chamberlain Corporation for 100 warhead metal parts to be produced from E52100 steel. Off-the-shelf, bearing quality 52100 steel was utilized for this contract. This contract was designed to have Chamberlain Corporation demonstrate the feasibility of producing one-piece warheads which would meet the engineering and fragmentation test requirements and perform in a manner comparable to the existing PMI warhead.

In this connection, a process was developed by the contractor (Figure 3) whereby bar stock was cut to proper length, cabbaged and warin (back) extruded. The resulting part was cup-shaped and drawn out to greater lengths through a series of cold forming operations. This elongated cylinder was cold-nosed to form the ogive curvature. The resulting part was hardened through heat treatment by furnace soaking, oil quenching and tempered back to produce a hardness of RC 52-58. This would offer fragmentation equivalent to the PMI warheads based on the series of fragmentation tests represented by Table 1.

Machining of the threaded areas at the nose and base end presented a problem due to this hardness; therefore, after tempering, the warhead extremities were softened, using an induction coil, to prepare these surfaces for threading.

An initial pilot quantity of 15 warheads was shipped to Picatinny Arsenal in May 1965 for inspection. After acceptance of dimensional and hydrostatic (5,000 psi) requirements, the hardness pattern was measured by cutting a center section through the length of the warhead and the hardness checked with a Rockwell tester on the ground cross-sectional surfaces (Figure 4A). Pit fragmentation tests were performed on two warheads. (Sample 3 and 4 of Tables 2-4) and the results were at least comparable with the PMI Warhead. (Note that sample 1 and 2 in these tables reflect the PMI design from original R&D data.) In addition, five warheads were drop-tested at 5- and 10-feet with no evidence of cracks.

Metallurgical tests also were performed on the initial samples. Figure 5 includes photographs of a sectioned part micro-etched to reveal flow lines from prior cold work. Figure 6 includes micrographs of the hard and soft zones which show very slight banding in the hardened area. Figure 7 includes micrographs of a typical hard-to-soft transition zone.

Five warheads were ballistically tested using Ballistic Research Laboratories' (BRL) box method and lethality data compared by ratio with PMI cast warheads (Table 5). Results of this test show the 52100 steel to be superior.

The balance of 85 warheads was produced and shipped to Picatinny Arsenal in July 1965 for high explosive (HE) loading and later subjected to a series of engineering environmental tests at Aberdeen Proving Ground (APG). The test program consisted of:

1. Jolt Test and Jumble Test followed by rocket firing in accordance with MIL-STD-300 and 301, respectively (five warheads for each test).
2. Temperature-Humidity Test (14-day cycle) in accordance with MIL-STD-304 followed by a 40-Foot Safety Drop Test at ambient temperature in accordance with MIL-STD-302 (five warheads).
3. A 40-Foot Safety Drop Test in accordance with MIL-STD-302 (five warheads).
4. A 5-Foot Drop Test in accordance with MIL-STD-358 followed by a rocket firing test (five warheads).
5. A 3-Day Temperature Storage Test in accordance with OPM-10-100 followed by Vibration Test (at temperature) in accordance with MIL-STD-303 (unpacked vertical orientation only with live XM423 Fuzes) followed by rocket firing test at temperature: 40 warheads at +155°F and 20 warheads at -65°F/

The results of this program were published as part of an APG report (Reference 1). Under "Summary of Results" this statement was made:

"The results of the various tests conducted indicate that 52100 Hypereutectoid Steel is safe to use as a substitute material for the 2.75-Inch HE XM151 LSFFAR Rocket Warhead. The only significant events occurred during bare 40-Foot Drop Tests. Two 52100 hypereutectoid steel shells, one of which had been subjected to temperature-humidity tests, broke but was safe to dispose of and there was no detonation or burning... These events merely indicate that the physical characteristics of these substitute materials are as safe as but not structurally comparable with those of PMI warheads."

Figure 21 shows the two broken warheads and Figure 8 is a summary of all firing tests.

Pilot Production Phase

As a result of the successful initial test phase, a follow-up pilot production contract was negotiated with Chamberlain Corporation for 51,000 warhead metal parts to be produced from 52100 Steel. The manufacturing process utilized hard tools and dies for this quantity compared to the R&D soft tooling used to produce the initial test samples. The number of draw operations was maintained at six to minimize the severity of cold work during each draw -- increasing the chances of a successful production process. Certain draw operations were consolidated when the contractor gained sufficient experience and confidence. The resulting process is outlined in Figure 9.

The heat-treatment process developed under this contract represented the most economical process for controlling the location of hardened areas. This was accomplished by utilizing a scanning type induction heat-treat process for selectively hardening the central portion of the warhead (7-1/2 inches wide) leaving both the nose and base ends soft for machining and threading operations. Two warheads were placed nose up on a fixture which "vertically traveled," allowing the warhead to pass through two sets of stationary coils. The first coil was for induction heating the warhead above the critical temperature while the second coil (designed with small port holes and connected to the quench liquid reservoir) was for quenching the warheads.

By programming the vertical movement of the Warheads with the heating/quenching coils, the major portion of the warheads were hardened, leaving the nose and base areas not heat-treated and soft.

The quenching liquid selected was a diluted solution of polyvinyl alcohol in water (plastic quench) which produced quenching characteristics similar to oil. Figure 10 shows the scan heat treatment equipment and Figure 11 shows sectioned warhead samples after this heat treatment. The hardness pattern produced from this induction scanning process and subsequently tempered, is in Figure 4B.

Because of delays by the induction equipment supplier, Chamberlain had the 15-warhead pilot lot heat-treated using the induction scan method on similar type equipment at the supplier's plant. This supplier was also a speciality induction heat-treater. Pilot lot inspection was performed at Picatinny Arsenal and the samples were approved for production. Warheads were also drop-tested.

and passed. When production started at Chamberlain, the first 500 warheads were shipped to this installation in February 1966 for confirmatory testing, in accordance with contractual requirements. The various stages of the production process and the finished warhead are shown in Figure 12 and 13 and the updated drawing used for this contract is in Figure 14.

Two warheads were pit fragmentation-tested and the results are in Tables 2-4 as Sample 5 and 6. Metallurgical tests were first performed to study the structure of the material in the finished state. The results (Figure 15) show the transition zone (Figure 15A) to be much more abrupt compared with transition zone of the initial test phase samples (Figure 7). This is due to the induction scanning process. Figure 15B revealed what appeared to be banding, running parallel to the center line of the warhead. A crack was observed on the inside surface (Figure 15C) and it appeared to propagate somewhat through the banded zone (Figure 15D). Investigating this further, a total of 48 warheads was examined for cracks on the inside and outside surfaces. Only one warhead had a metal defect which appeared to be more of a lap.

The presence of banding, together with the crack reported in Figure 15C and D found in a warhead not dropped, raised a concern over the possible presence of retained austenite. If present, retained austenite could lead to structural failure during storage or firing due to time dependent phase transitions. The unstable austenite would in such instances transform to untempered martensite with an associated volume expansion. If this process did occur it would cause cracks; the cracks could propagate along a brittle banding area resulting in a severe safety hazard. X-ray diffraction techniques were used to measure the austenite in both initial test samples and production samples (Reference 2). Retained austenite was found to be below the minimum detectable level, believed to be between 0.5 and 1% (Figure 23).

Five-foot bare drop tests of inert-loaded warheads were performed to evaluate the safety of the hardware produced by the new process. The banding noted previously was considered a detriment to normal safety and handling. Of five warheads dropped -- each in a different orientation (horizontal, vertical nose down, vertical base down, nose down 45°, base down 45° -- the one warhead which was dropped horizontally cracked. As a result additional tests were scheduled for both inert-loaded and empty warhead metal parts to be dropped horizontally (Figure 16). Hardness checks were made on the 40-Foot

and 5-Foot Drop Test samples (Figure 4C left and 4C right, respectively). Both warheads met the hardness requirements of RC 52-58.

Metallurgical Analysis

Subsequently, a metallurgical analysis was made of a typical crack zone. Figure 17 shows a typical condition of the crack parallel to or possibly propagating through a band. Further micrographs were taken of the specimen to study the banding in three dimensional planes (Figure 18). It can be seen that the banding is "rod like" parallel to the center line of the warhead. It should be noted that banding was never observed to any appreciable degree in the initial test phase samples, as evidenced by a review of Figure 6. This was confirmed by studying additional samples of both old and new warheads (Figure 19).

A comparison of drop test fracture patterns was made between present production warheads and the two warheads which broke on 40-Foot Bare Drop Tests during the initial test phase (Figure 20 and 21). The difference in break pattern appears to offer additional evidence that the banding in the production warheads offered brittle paths for crack propagation.

A starting slug was obtained from the production stockpile at Chamberlain Corporation. Metallographic samples were prepared and examined and banding was present, parallel to the slug center line which also is parallel to the direction of subsequent metal working. This banding (Figure 22) remains in the warheads throughout the entire metal working process and is evidently drawn and attenuated into concentrated brittle stringers (evidenced by Figure 15B) compared with the discrete carbide particles of the banding in the starting slug of Figure 22 (500X).

Physical tests were conducted on specimens representing initial test and production samples with these results:

TENSILE TESTS

	Yield Strength psi	Tensile Strength psi	Elongation (%)	Reduction in Area (%)
Initial Test Samples	264,000	299,000	3.2	21.0
	264,000	299,400	2.4	14.0
Present Production Samples	First two samples broke in threaded area. However, Y.S. reached 282,500 and 281,000 psi, respectively.			

CHARPY IMPACT TESTS

	Charpy Value (ft-lbs)			Average
Initial Test Samples	1.72	1.44	1.80	1.65
Production Samples	0.80	0.95	0.38	0.71

At the same hardness level, the initial test samples offered twice the impact value as the production samples. Broken charpy surfaces were prepared for electron microscopy to study the topography of the fracture surfaces. By the use of this technique of electron fractography it was hoped to get further insight into the brittleness of the materials. Figure 24 shows the fractographs for both warhead samples. Actual topographical contour designs for fracture surfaces were classified into ductile fracture, cleavage (brittle) fracture, etc. The outstanding feature noted in both fractographs of Figure 24 is "dimpling" or "dimpled rupture" which indicates ductile fracture and is characterized by circular or semi-circular markings. However, the initial test samples showed a greater amount of this dimpled rupture. This mode of fracture is quite common to a wide variety of materials, including high strength steel. The same mechanism of fracture is active and the same general appearance results regardless of strength level. Both fractographs also show some evidence of cleavage or quasi-cleavage, but here the production sample showed a greater tendency toward this mode of fracture as evidence by the "canal" pattern in the top center of the production fractograph.

At the time this investigation was being conducted to determine the cause of brittleness in the conventionally heat-treated production warheads, other warheads were being heat-treated in various ways to eliminate brittleness to satisfy the 5 - and 10 - Foot Drop Tests. These test results (Figure 25) revealed some correlation between hardness and drop test results -- generally with the harder warheads showing the greater number of failures. Drop Test Sample 8 and 9 representing the production process but tempered back to a lower hardness (R_c 44-49 Figure 4D and E) showed some possibilities, and representative warheads were pit fragmentation-tested (Samples 7-10 of Tables 2-4). The poor fragmentation results of these rounds compared with the initial test (Samples 3 and 4 of Tables 2-4), could not justify production of the softer warheads.

Another series of warheads exhibiting strong possibilities by passing drop tests were Samples 26 and 27 of Table 25. These warheads were normalized (air cooled) from 1650°F, developing a hardness range of R_c 23-29 (Figure 4F). It was hoped that this heat treatment would produce a network of some brittle carbide along the grain boundary and that the fragmentation would approach our initial test samples (3 and 4 of Tables 2-4). The microstructure of these samples revealed that only a slight network developed (Figure 26).

Representative warheads were pit fragmentation-tested as Sample 11 and 12 of Tables 2-4. Fragmentation was very poor and could be attributed to this heat treatment.

Another normalized treatment at 1750°F did produce a more definite carbide network (Figure 26), but warheads failed the Drop Tests (Figure 25, Test 30). However when the warheads were machined prior to normalizing, they passed drop tests (Figure 25, Test 28 and 29). A decarburized layer was present on the outside surface and may have contributed to the end result by cushioning the drop test impact. This was not pursued any further and no fragmentation tests were performed on these warheads.

A final test series was conducted for general information by Picatinny Arsenal on production warheads, which were subjected to a carbide network heat treatment. The hardness pattern after heat treatment is in Figure 4G. Fragmentation tests were conducted (Sample 13 and 14 in Tables 2-4) and results were poor compared with production warheads. This could have resulted from poor response to heat treatment. It should be noted that an extended soak time was provided to destroy the martensitic microstructure. Photomicrographs of these warheads (Figure 27) show a network at 500x, but possibly not sufficient to produce the superior fragmentation for which this heat treatment is known. Note also the band in Figure 27, 250x, and its response to this heat treatment.

A summary of all mechanical tests is in Figure 28.

(U) OBSERVATIONS AND COMMENTS

The quench and tempered warheads of R_c 55-56 produced originally as initial test samples survived 5- and 10-Foot Drop Tests and passed a complete engineering test program. Fragmentation was as good as PMI warheads. Micrographs showed almost no sign of any banding.

Subsequent production warheads of R_c 56-58 produced from different heats of 52100 steel, broke at 3-Foot Drop Tests. Micrographs indicated that banding was present in warheads and further that cracks are propagating along these bands. The banding may or may not have initiated the cracks. The cracks may have been initiated during heat treatment, but this was never fully ascertained. However, it appears that the cracks were propagating along the brittle banding paths.

Charpy impact tests show some correlation with Drop Test results. Drop tests in our program were a useful tool and should be used more frequently.

The 52100 steel was successfully warm cupped and cold drawn to produce the 2.75-inch warhead to required dimensions.

Further work could be performed to develop a one-piece 2.75-inch warhead. One approach could be an investigation of the 52100 steel 1750°F normalized warhead described briefly in this report. A carbide network was formed and fragmentation may be comparable with the PMI warhead.

A better approach may be to investigate alternate steels, such as 1340 and 4150 which are being evaluated for other shell applications.

Finally, it is hoped that this report enhanced the information on the deleterious effects of banding.

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REFERENCES

1. Engineer Design Test of Substitute Material for XM151 Warhead, HE for 2.75-Inch LSFFAR Rocket (Safety Evaluation), Firing Record R-3653 Aberdeen Proving Ground, Maryland, November 1965.
2. H.R. Erard, Advances in X-Ray Analysis, Volume 7, "Techniques of Measuring Low Percentages of Retained Austenite Using Filtered X-Ray Radiation and an X-Ray Diffractometer," pp. 256-265, 1963.

APPENDICES

APPENDIX A

Figures

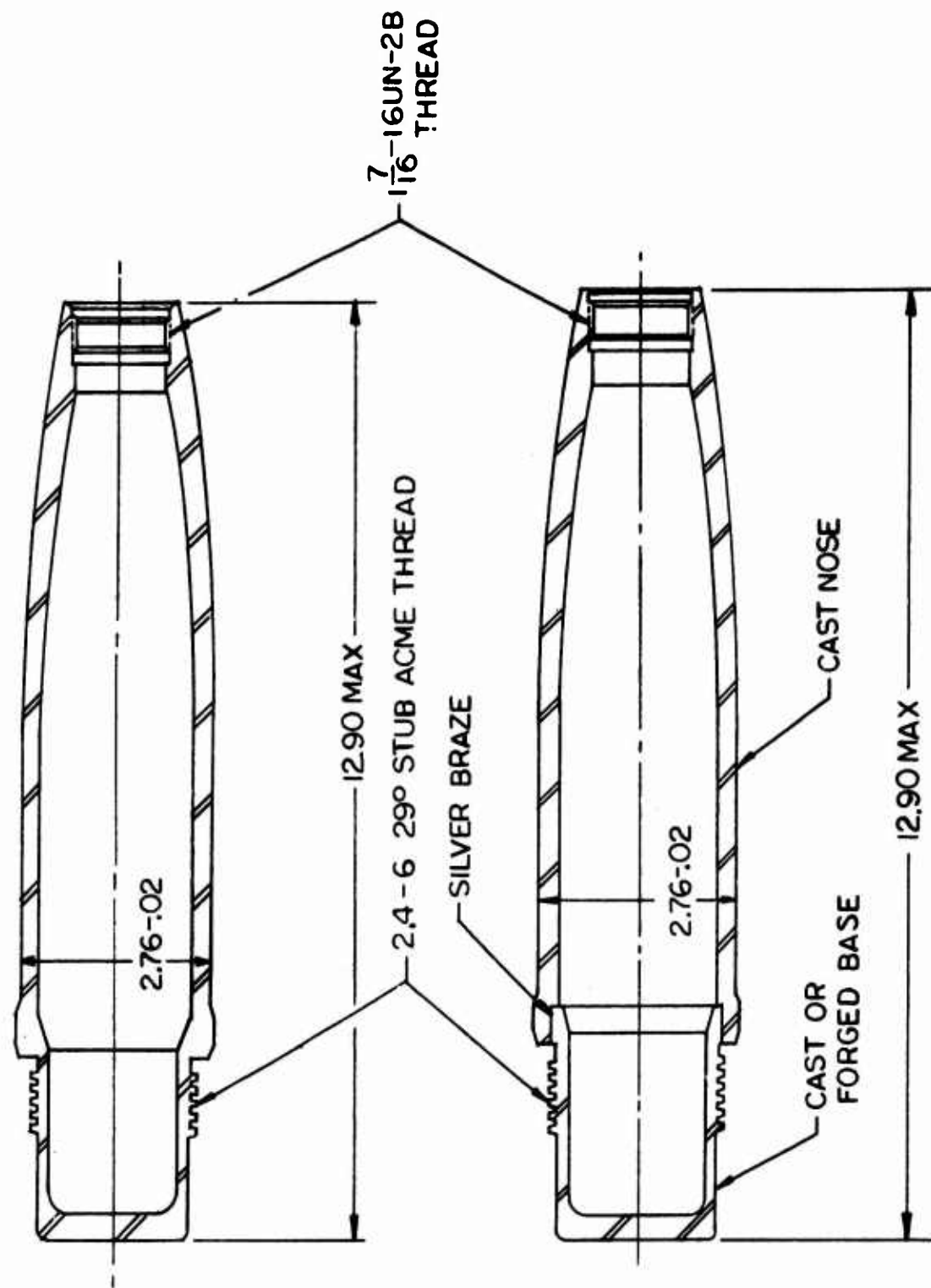


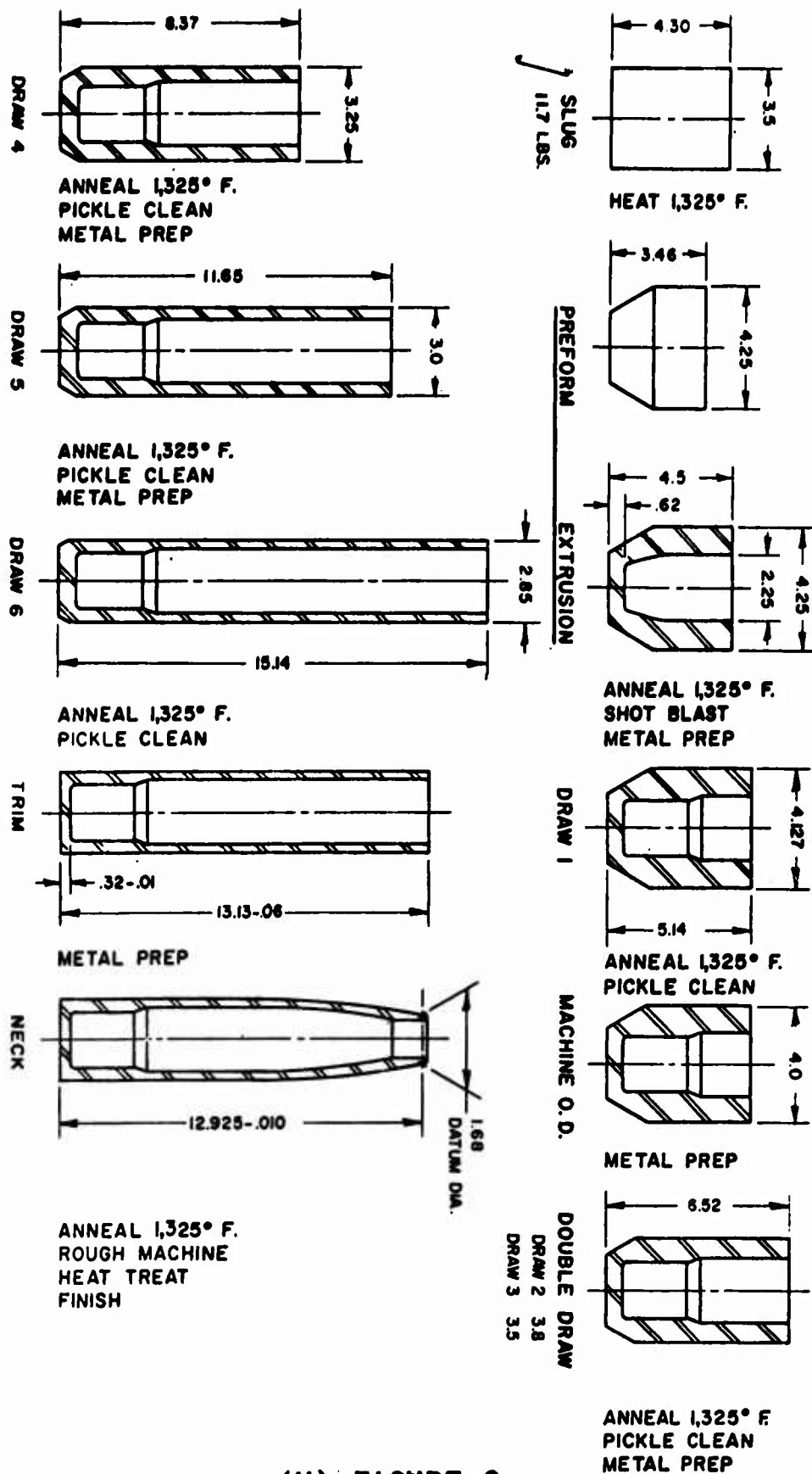
FIG. 1

COMPARISON OF ONE-PIECE, WARM CUP, COLD DRAWN WARHEAD
WITH TWO-PIECE WARHEAD, 2.75 INCH ROCKET, XM151



2.75 INCH ROCKET

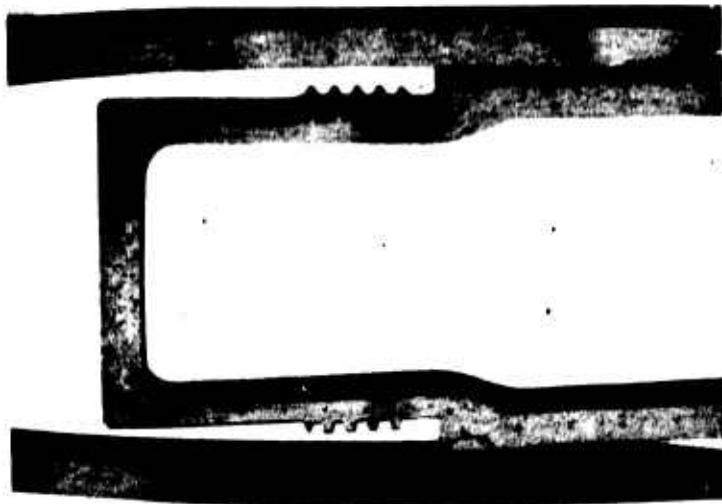
FIG 2



(U) FIGURE 3
DIAGRAM OF WARM CUP-COLD DRAW
METALWORKING PROCESS

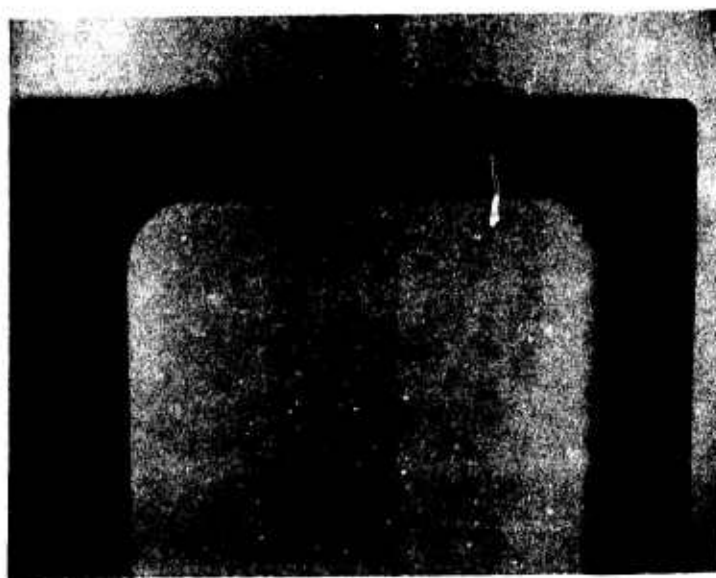
ROCKWELL C
2.75 RKT WHD

FIG. 4
HARDNESS PATTERNS FOR VARIOUS HEAT TREATED WARHEADS



A.

Cross-Section of Etched Warhead Surfaces

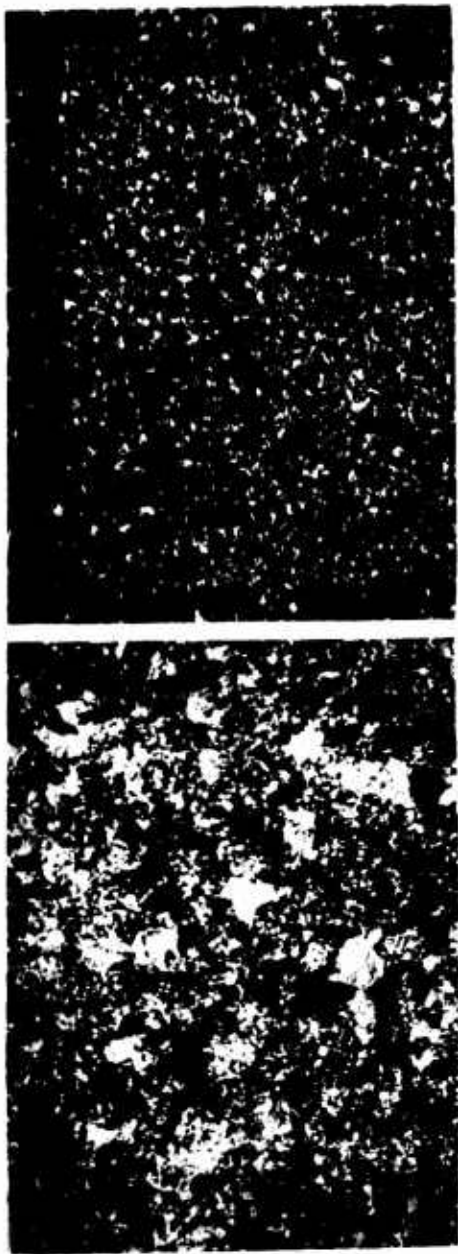


B.

Cross-Section of Etched Base End Surfaces

(U) FIGURE 5
MACRO-ETCH PHOTOGRAPHS SHOWING METAL
FLOW TYPICAL OF THESE 100 WARHEADS

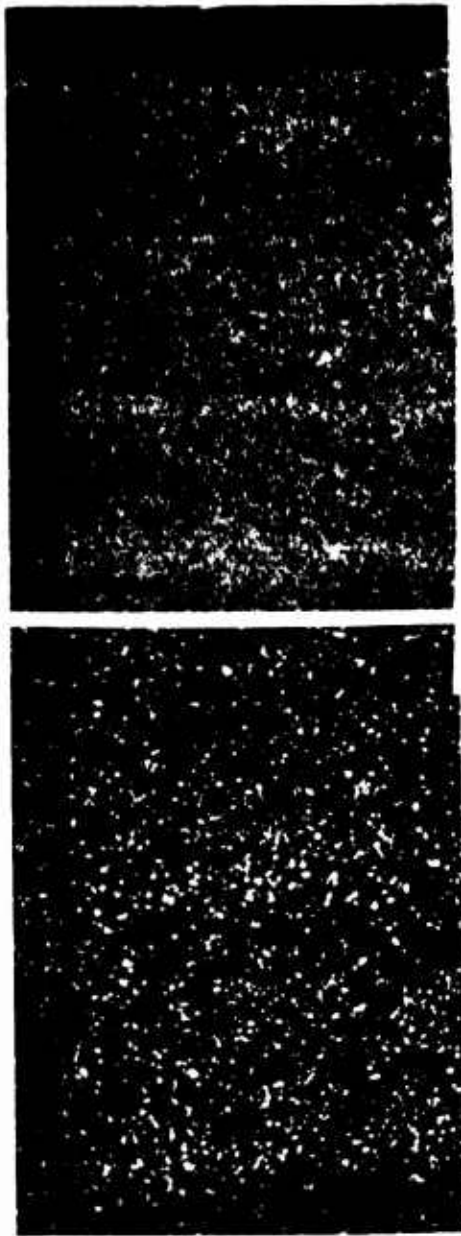
(U) FIGURE 6



500X

Soft Area (about RC 20) Produced by First Hardening Area followed by induction softening

100X

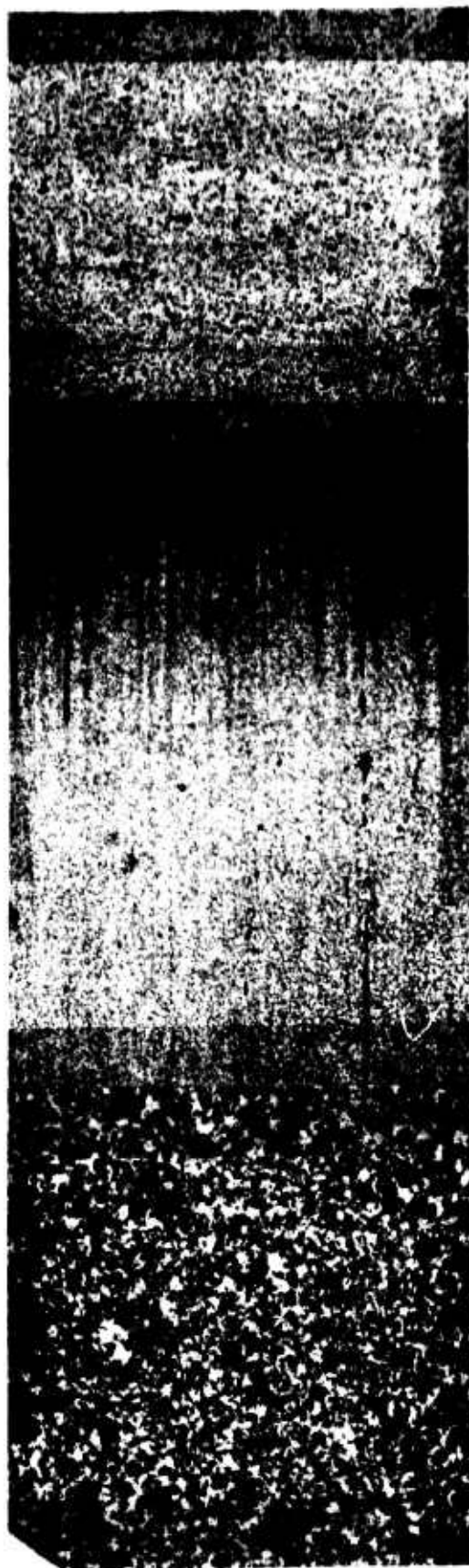


500X

Hard Area (about RC 55-56) produced by hardening, (oil quench and temper)

100X

MICROGRAPHS OF SOFT AREAS (NOSE AND BASE ENDS) AND HARD AREAS



Hard Zone

75X

Transition Area

50X

Soft Zone

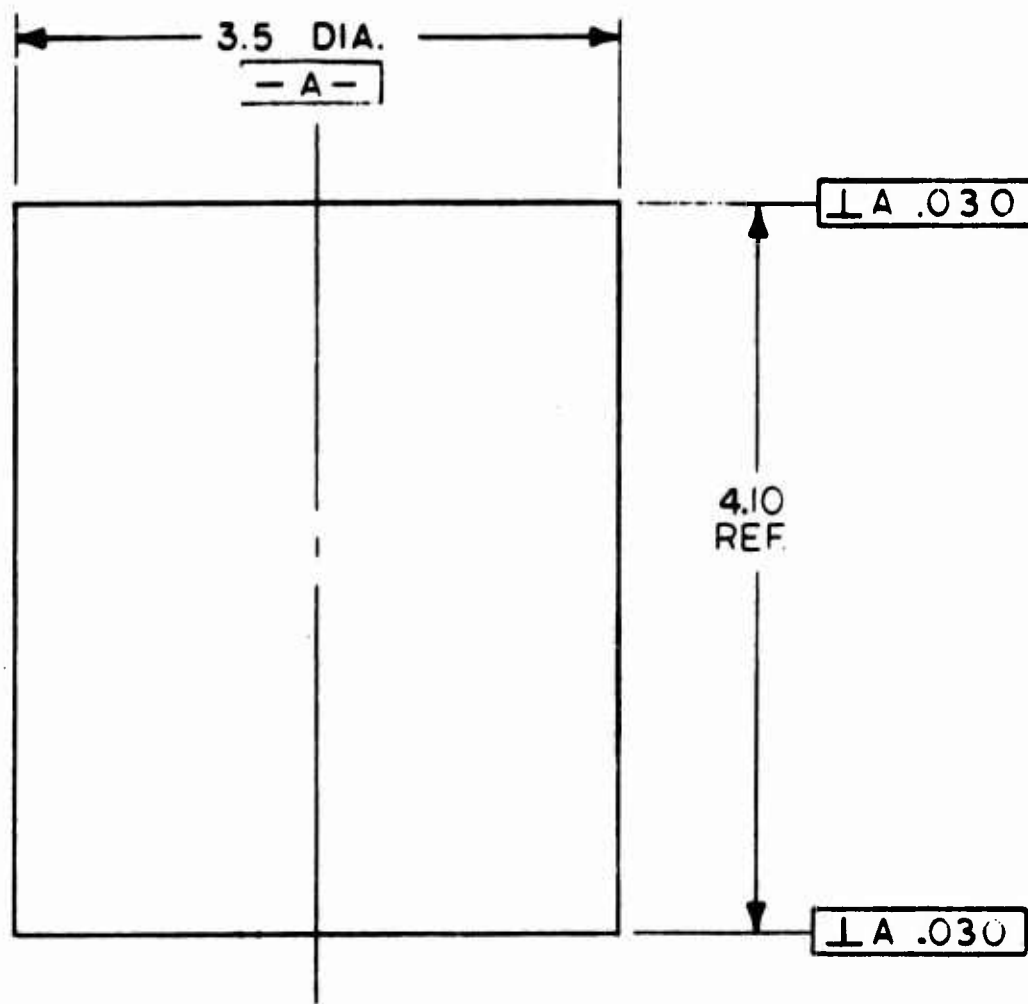
75X

(U) FIGURE 7
TRANSITION ZONE AT BASE END (SHOULDER)
PRODUCED BY INDUCTION HEAT TREATMENT 25

AMT	Test Prior to Field Firing	Material
5	Jolt	52100
5	Jumble	52100
5	5-Foot Drop	52100
20	Temperature Vibration Fired cold (-65°F)	52100
40	Temperature Vibration Fired hot (+155°F)	52100

(U) FIGURE 8

SUMMARY OF FIRING TESTS
AT
ABERDEEN PROVING GROUND
FOR
2.75-INCH ROCKET MOTORS



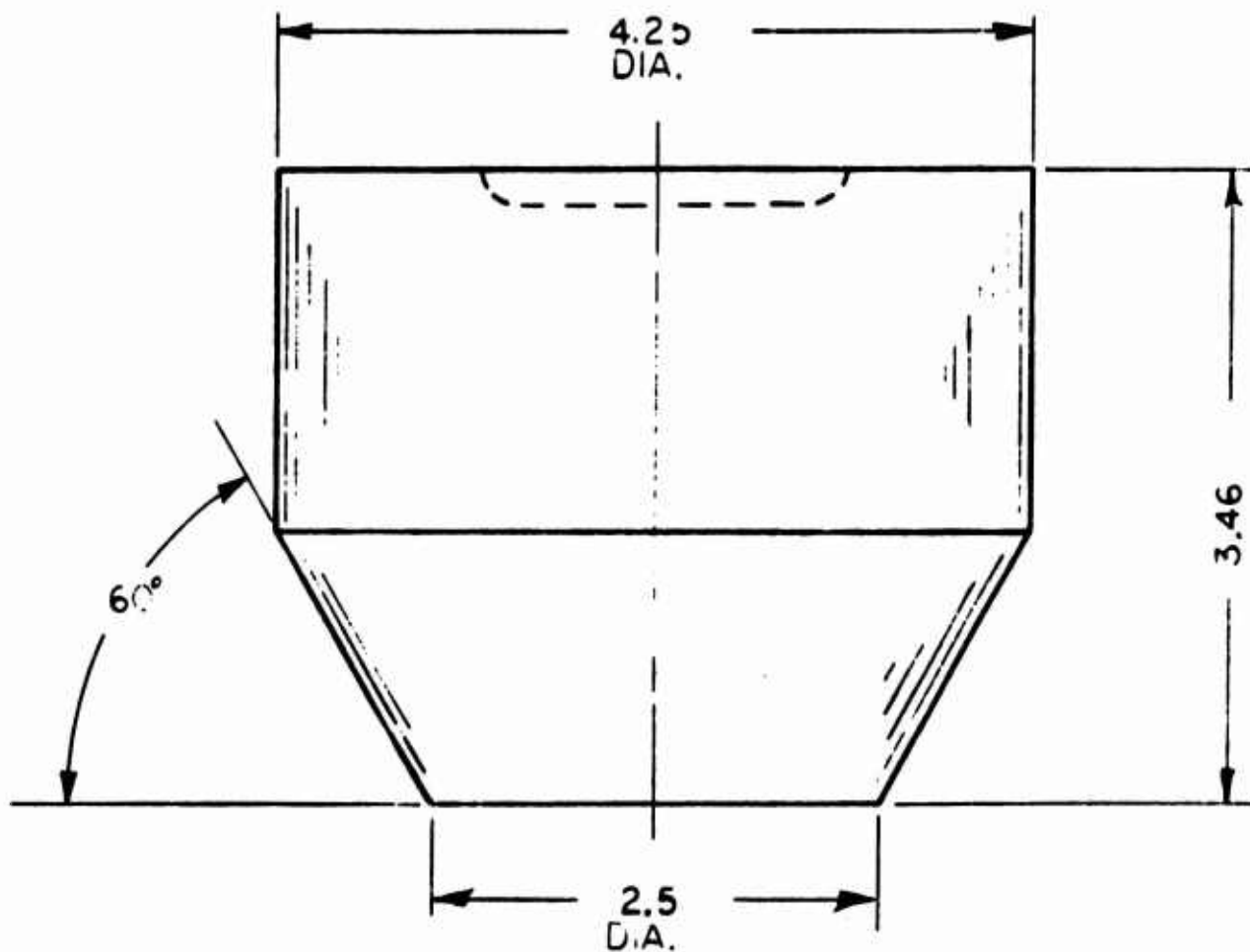
OPERATION #5 — SAW SLUG

MATERIAL: 52100

WEIGHT: 11.2 LBS. + .3 LBS.

SAW: KALAMAZOO

(U) FIGURE 9
 PRODUCTION PROCESS FOR ONE-PIECE 2.75-INCH
 WARHEAD METAL PARTS DEVELOPED BY CHAMBERLAIN
 CORPORATION



OPERATION #10 - CABBAGE

PRESS: ERIE 100 TON HYD

DIE: LM 109-5

PUNCH: LM 109-12

TONNAGE: 500

OPERATION #10

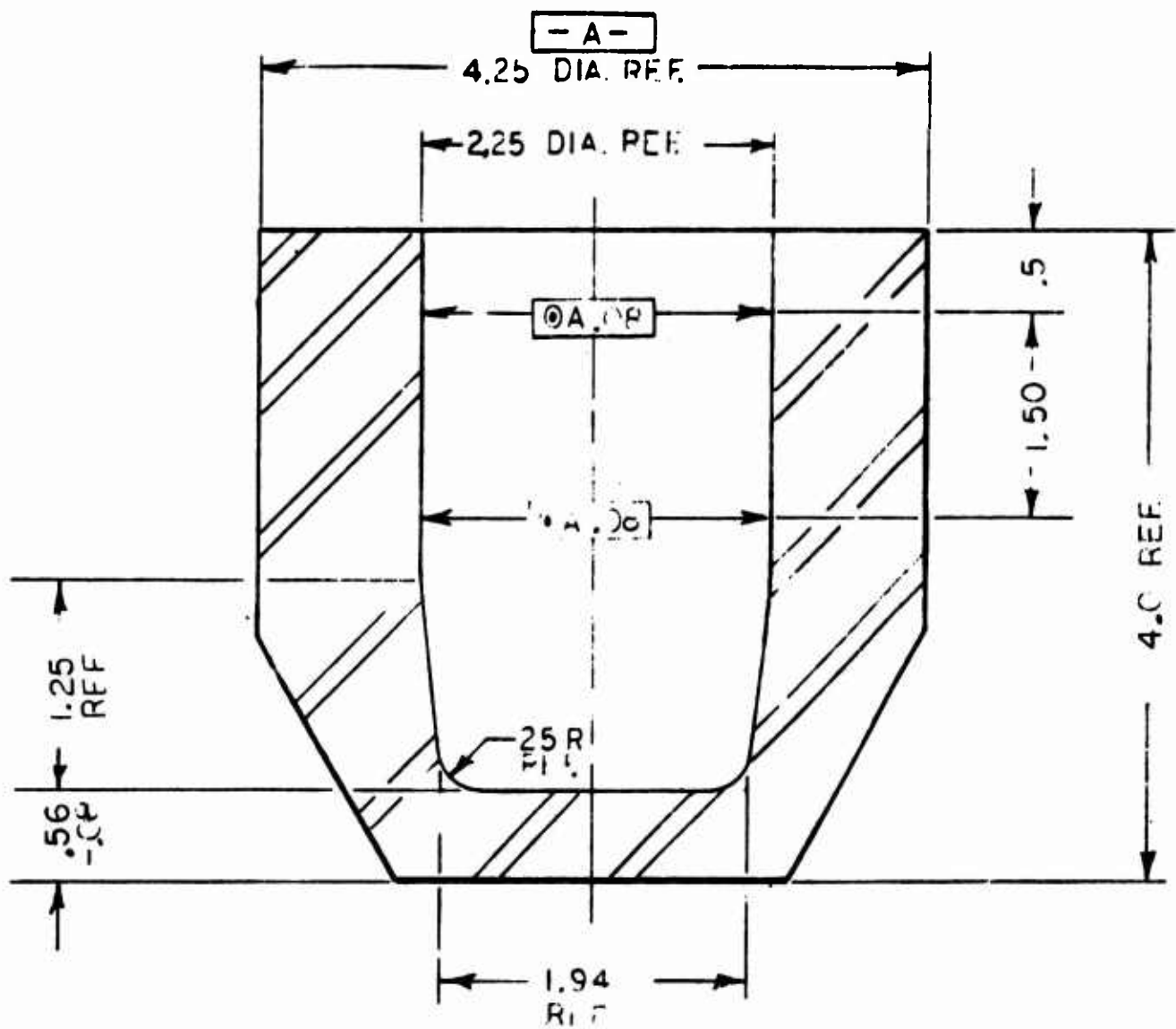
PREPARATION: HEAT TO 1350° TO 1370° F 2½ HRS

FURNACE: SURF. COMB. FURNACE

(AFTER CABBAGE SHUTTLE PUNCH FOR
EXTRUSION ON SAME HEAT)

28

(U) FIGURE 9 (CONT'D)



OPERATION #10 - EXTRUSION

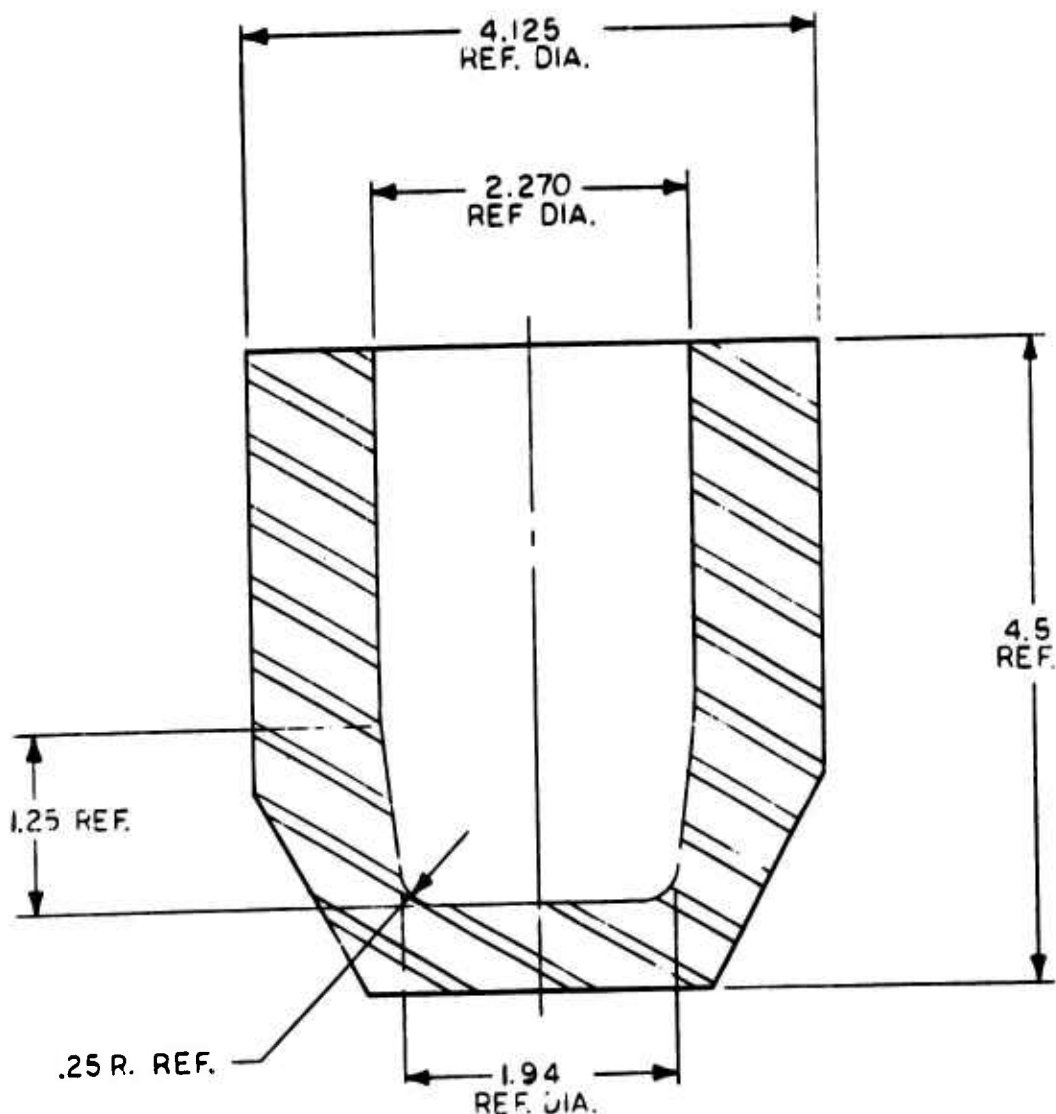
PRESS: ERIE 1000 TON HYD

DIE: LM 109-5

PUNCH: LM 109-13 (REV. A)

TONNAGE: 300

(U) FIGURE 9 (CONT'D)



OPERATION #30 - 1" COLD DRAW

PRESS: 150-200 TON

DIE: LM 114-14-1

PUNCH: LM 114-13

TONNAGE: 80

PREPARATION

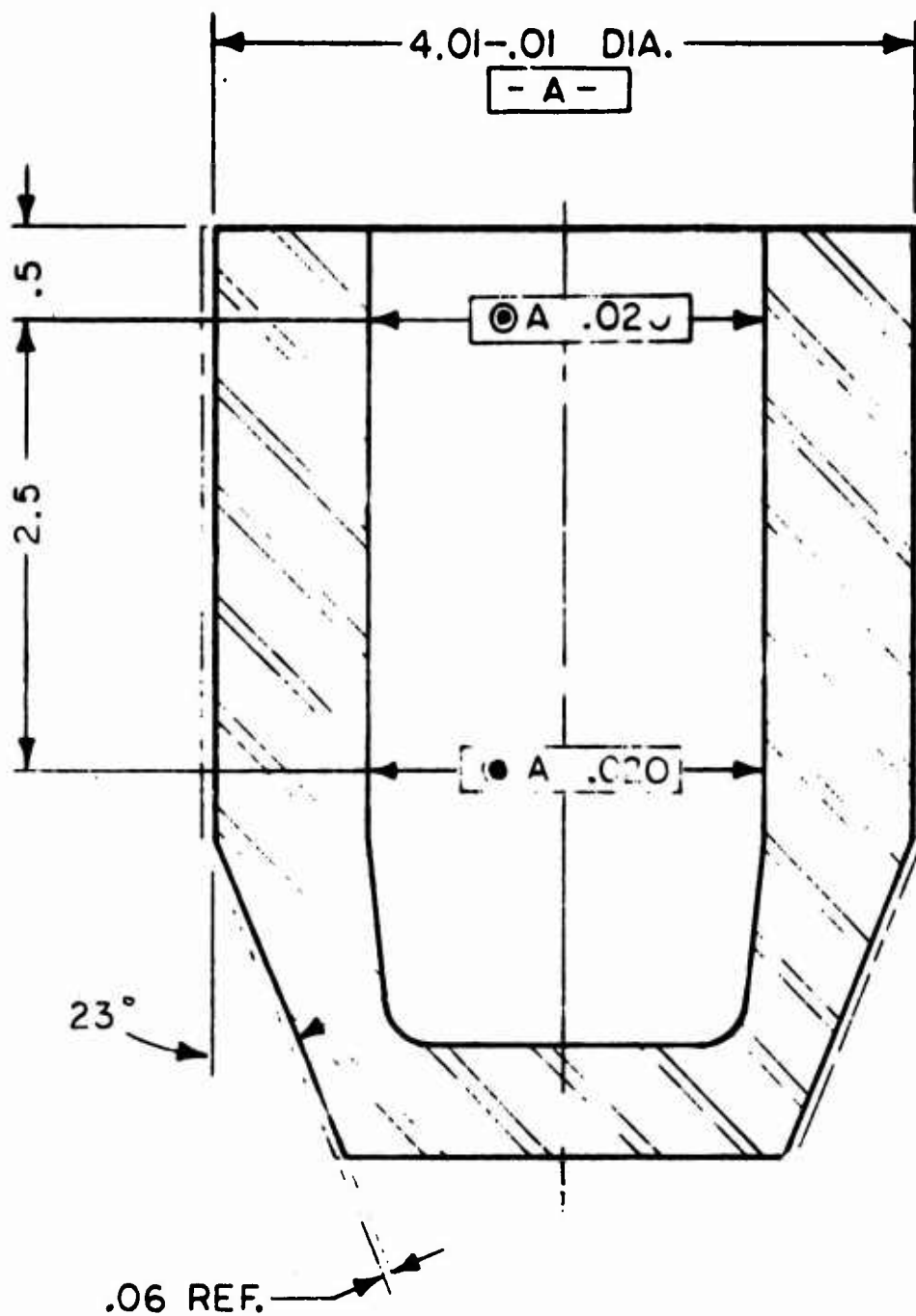
OPERATION #12: SHOT BLAST CAVITY - PANGBORN

OPERATION #15: SHOT BLAST OUTSIDE - ROTOBLAST

OPERATION #20: ISOTHERMAL ANNEAL - R&S FURNACE

OPERATION #25: METAL PREP-"U" BLDG. SYSTEM

(U) FIGURE 9 (CONT'D)

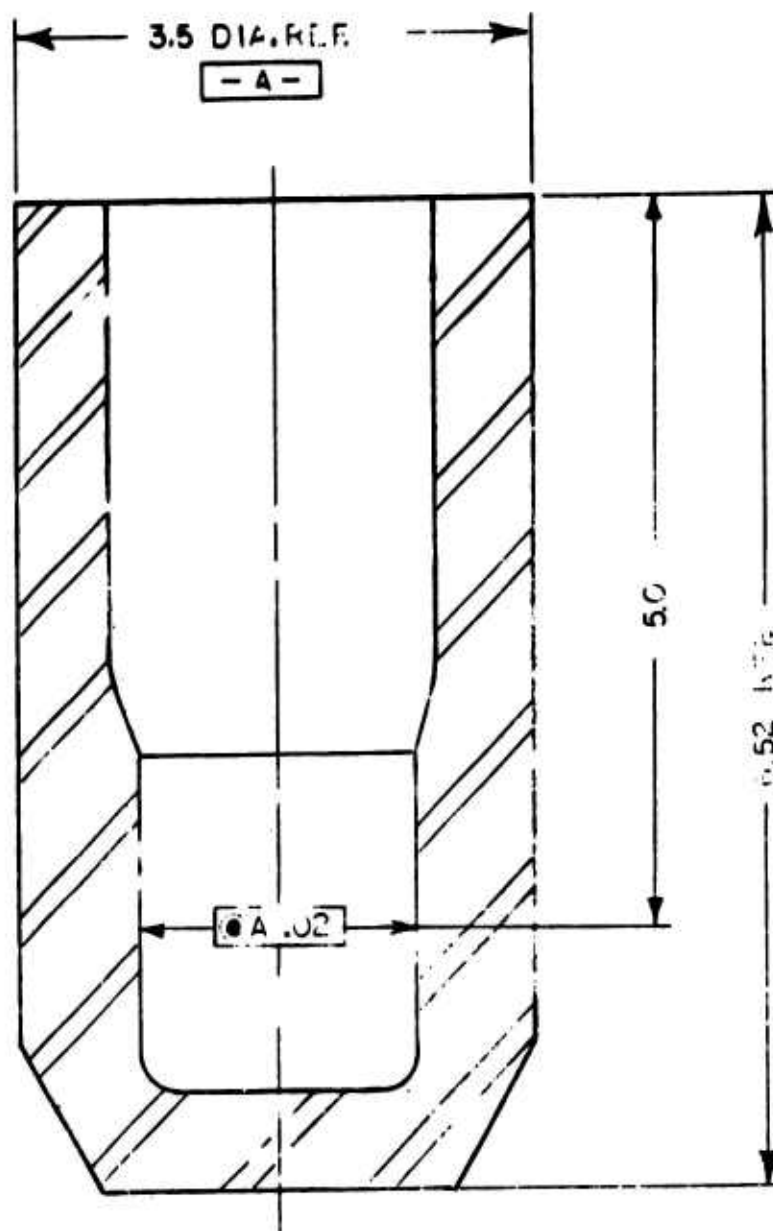


OPERATION #35 - MACHINE O.D.

MACHINE: SUNDSTRAND 1882

TRIM TO WEIGHT 9.8 LBS. MIN.

(U) FIGURE 9 (CONT'D)



OPERATION #5 - 2ND 3RD COLD DRAW

PRESS: 2 TON ELVES HYD

DIE: LM 114-14-2+3

PUNCH: LM 114-11

TUNNAGE: 150

PREPARATION

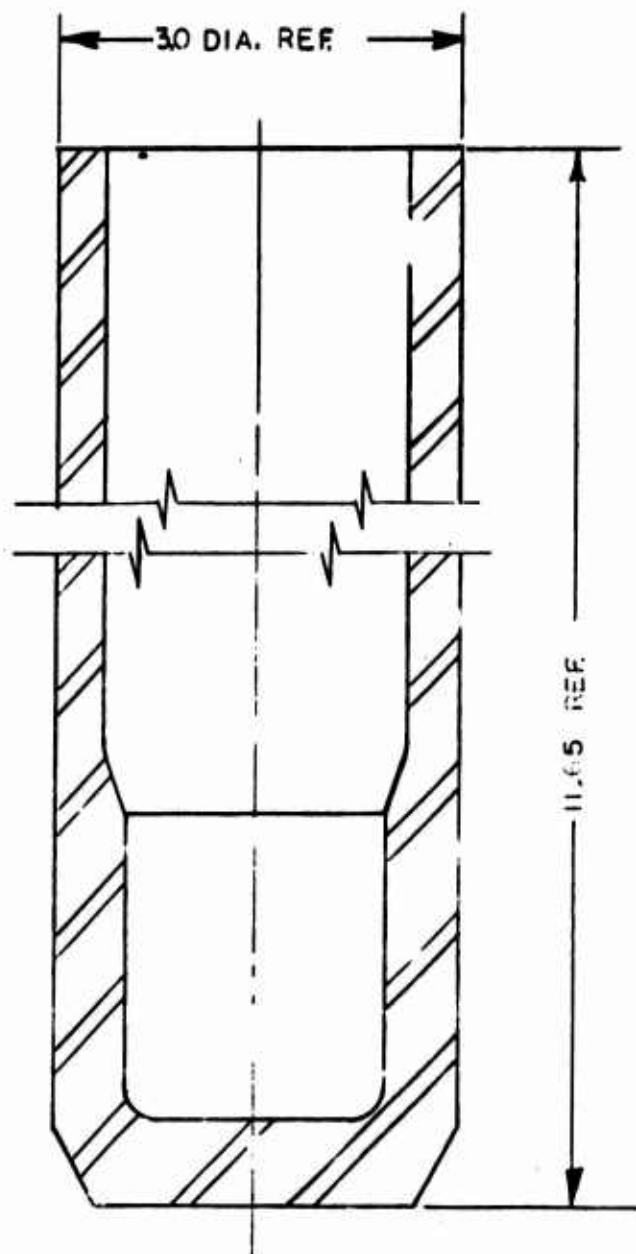
OPERATION #40:

ISOTHERMAL ANNEAL R & S FURNACE

OPERATION #45:

METAL PREP

(U) FIGURE 9 (CONT'D)



OPERATION #95 4+5TH DOUBLE COLD DRAW

PRESS: HYD 300 TON VERSION

DIE: LM-114-12-4+5

PUNCH: LM 114-11

TOINAGE: 125

PREPARATION

OPERATION #85:

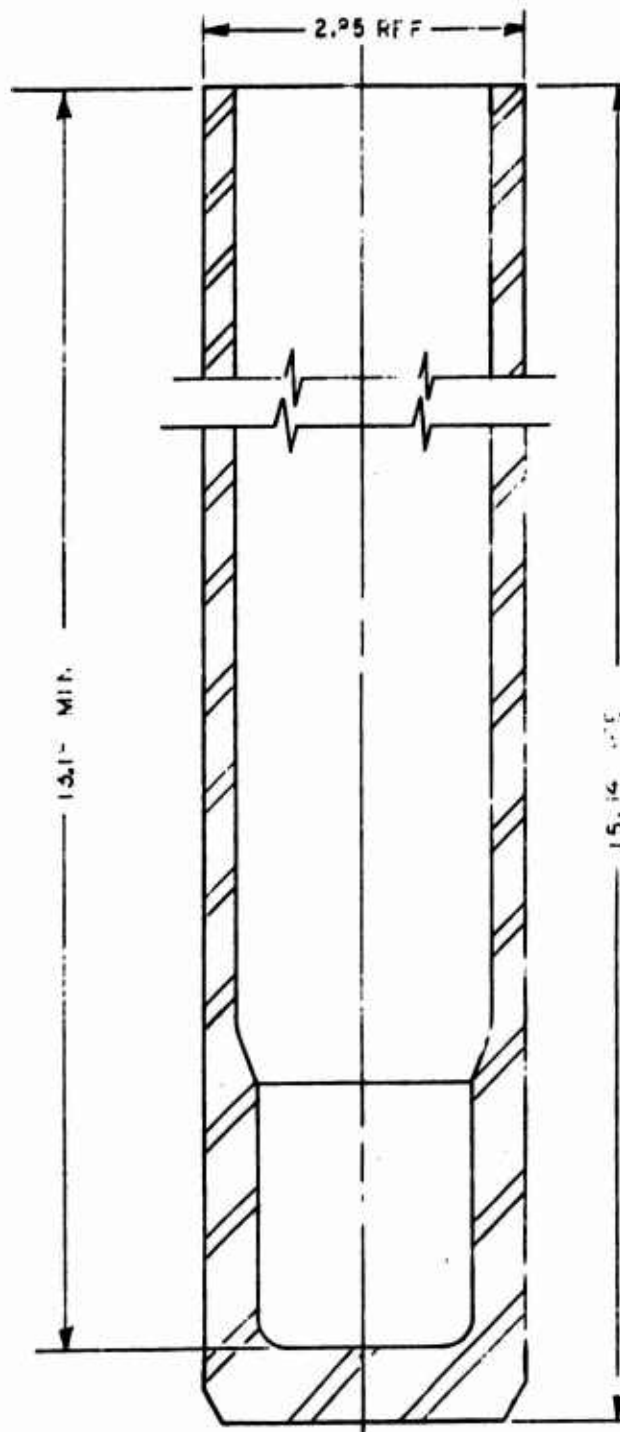
ISOTHERMAL ANNEAL R & S FURNACE

OPERATION #90:

METAL PREP

33

(U) FIGURE 9 (CONTD)



OPERATION *112 - 6" COLD DRAW

PRESS: HYD 200 TON BLISS

DIE: LM114-14-6

PUNCH: LM114-11

TONNAGE: 125

PREPARATION

OPERATION *100:

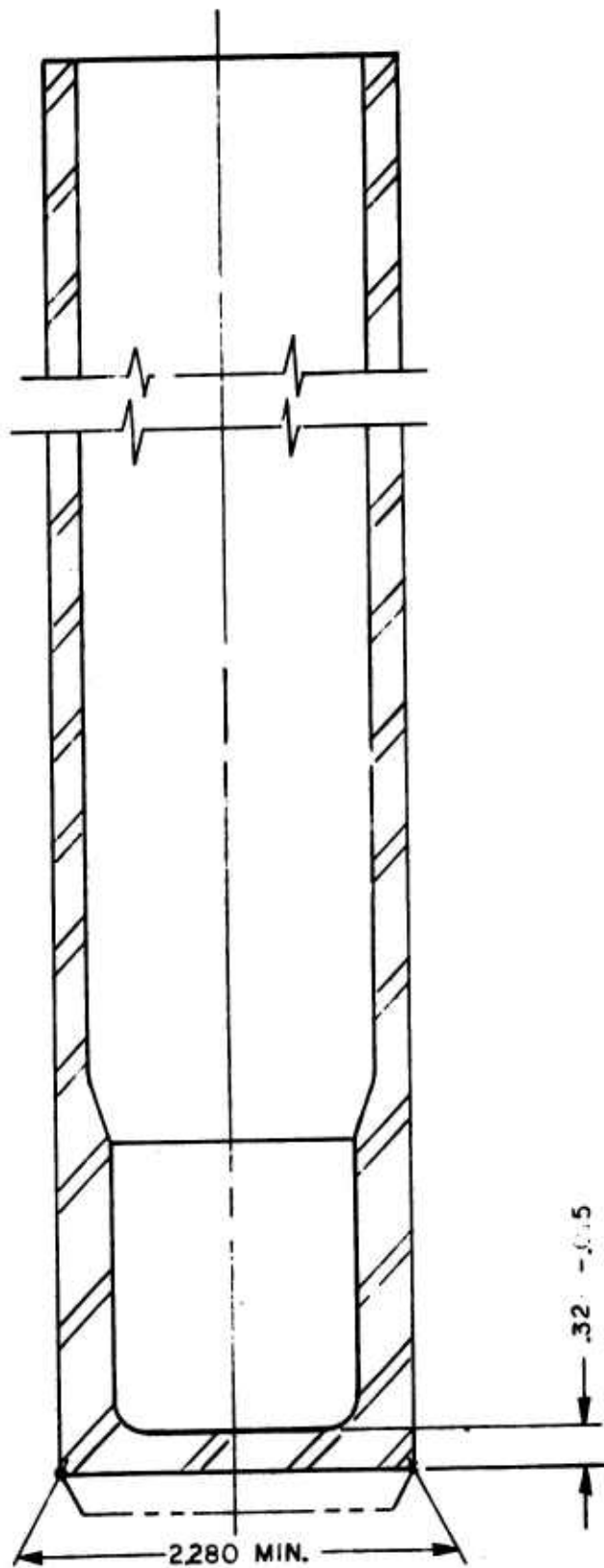
ANNEAL 1320° TO 1340° F 3 HRS DREVER

OPERATION *105:

34

METAL PREP

(U) FIGURE 9(CONTD)



OPERATION #120 - TRIM BASE END

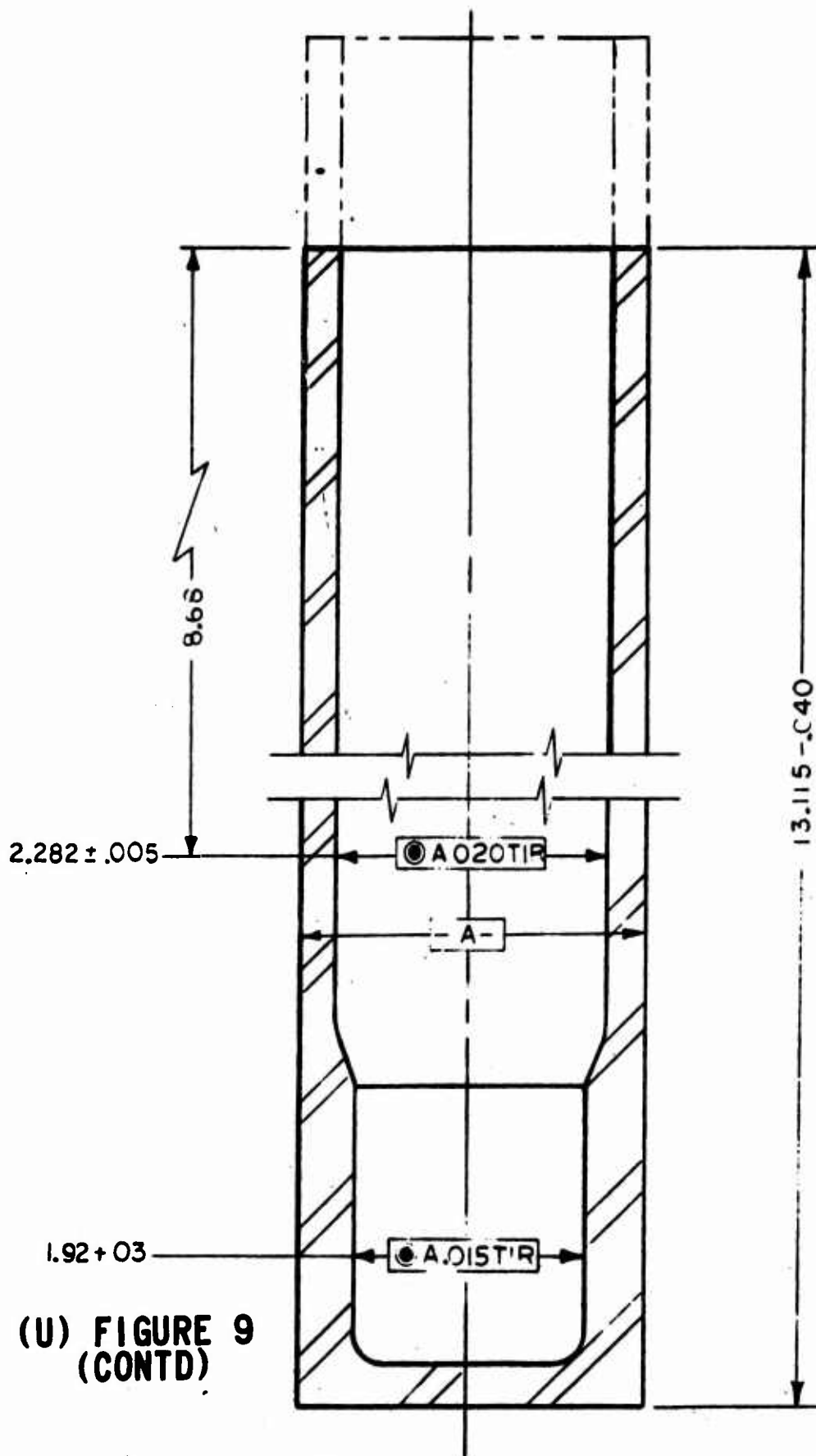
MACH: CUNSTRAND 10 - SERIAL NO. 17-1761₃₅

PREPARATION

(U) FIGURE 9(CONTD)

OPERATION #115

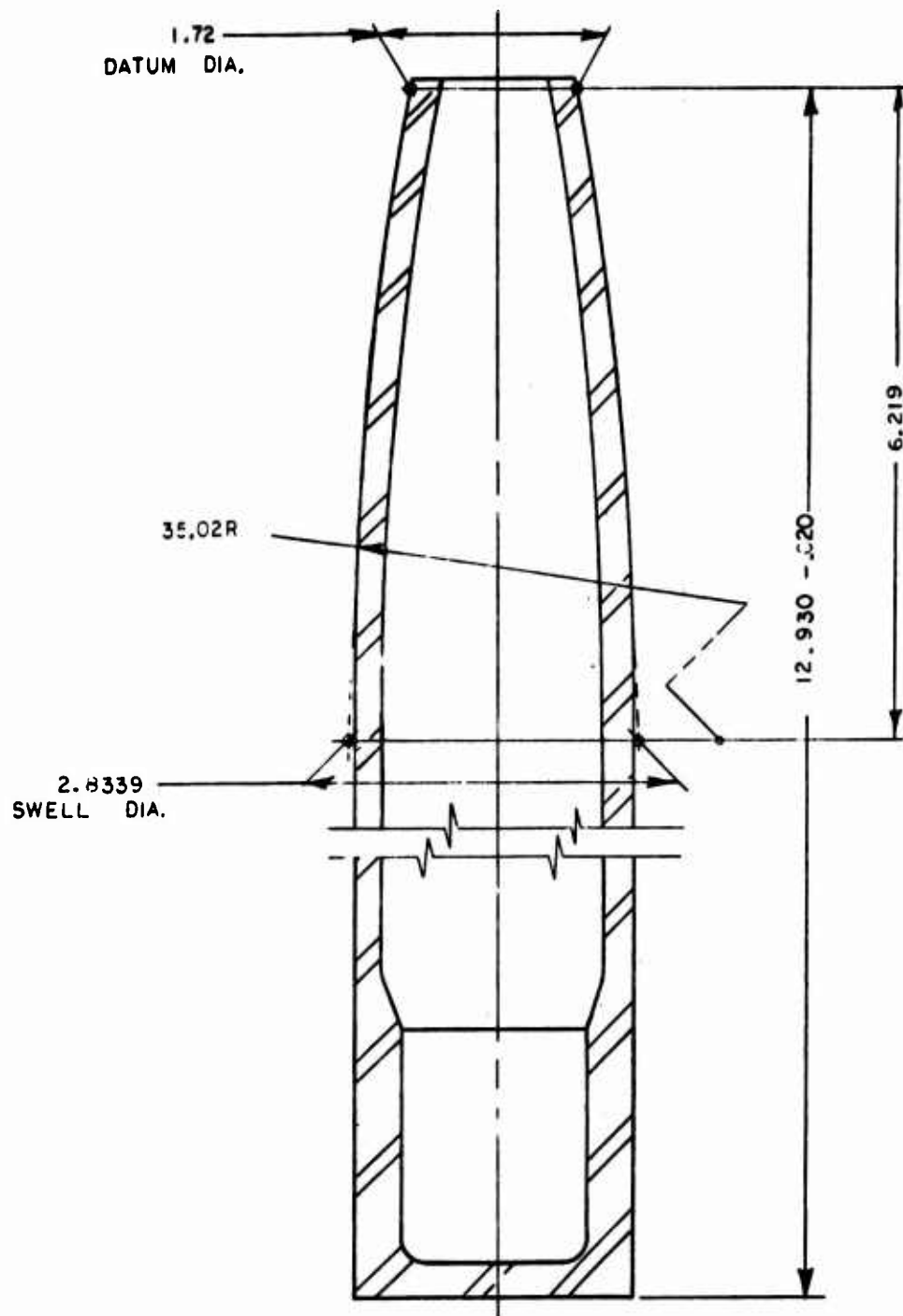
ANNEAL: 1320° TO 1340° F 3 HRS REVERSE



(U) FIGURE 9
(CONTD)

OPERATION #125 - TRIM NOSE END

³⁶ MACH: SUNSTRAND - 10 SERIAL NO. 10-1622



OPERATION # 135 NECK

PRESS: HYD 200 TON ELMES

DIE: } LM 115 ASS'Y

PUNCH: }

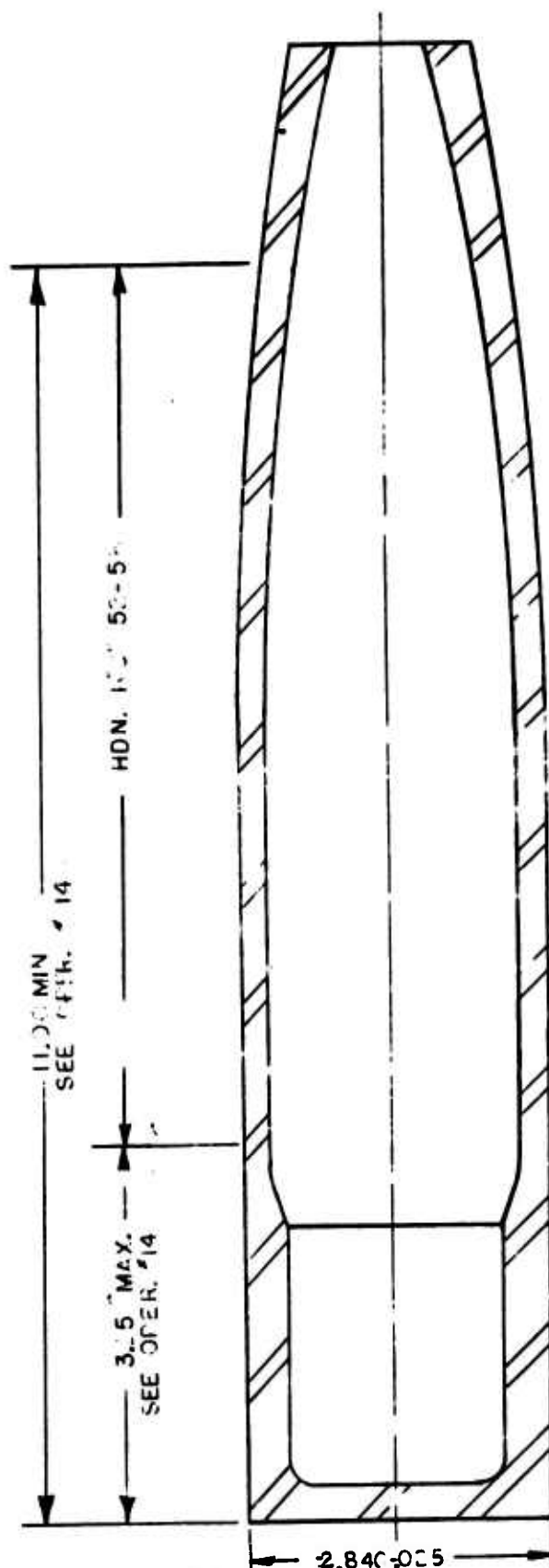
TONNAGE: 100

PREPARATION

OPERATION # 130
METAL PREP

(U) FIGURE 9 (CONTD)

'U' BLOG SYSTEM



OPERATION #145 - GRIND - 0.2

PREPARATION

(U) FIGURE 9(CONTD)

OPERATION #140:

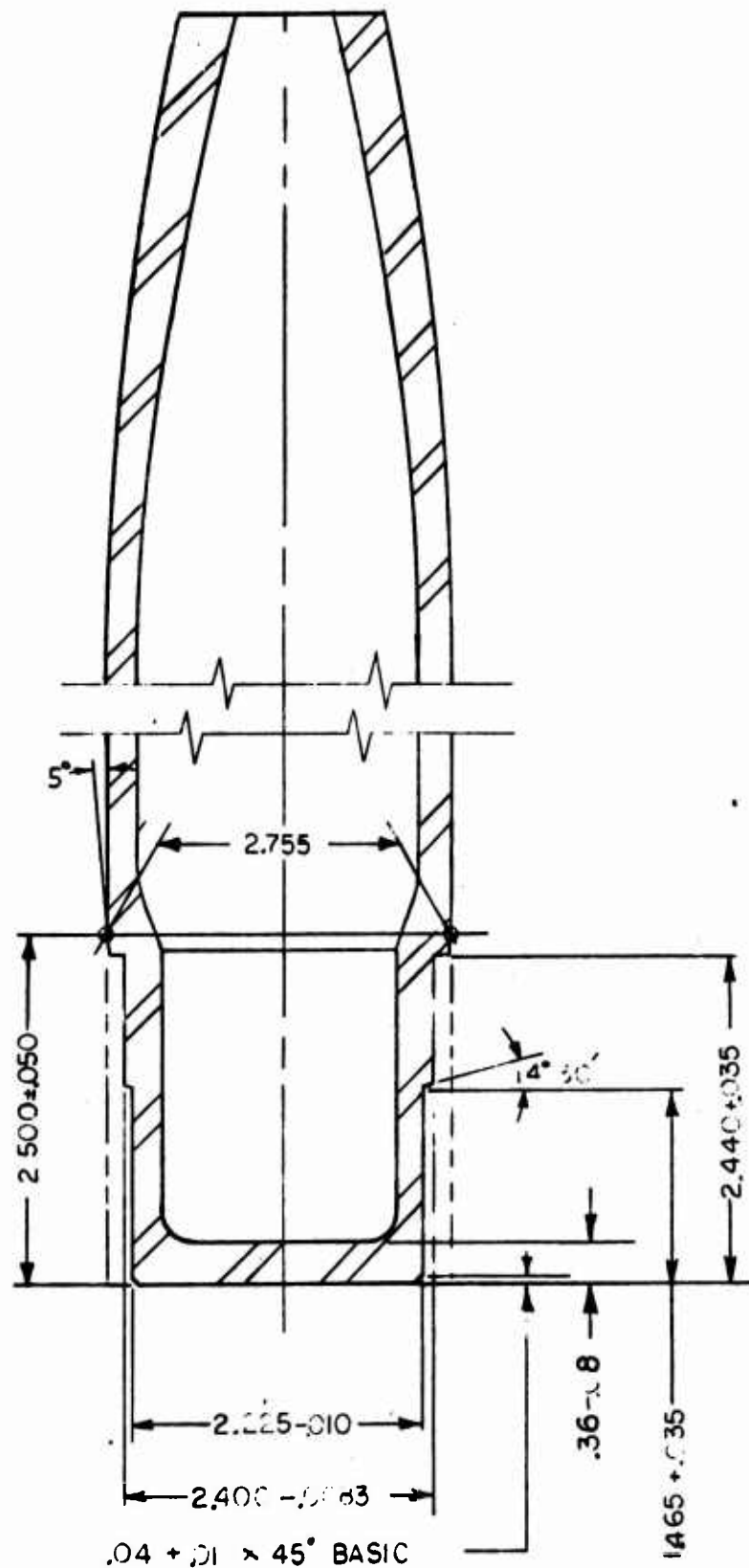
HEAT TREAT R°C 60 MIN. (2040 MIN. OD)

OPERATION #142:

38

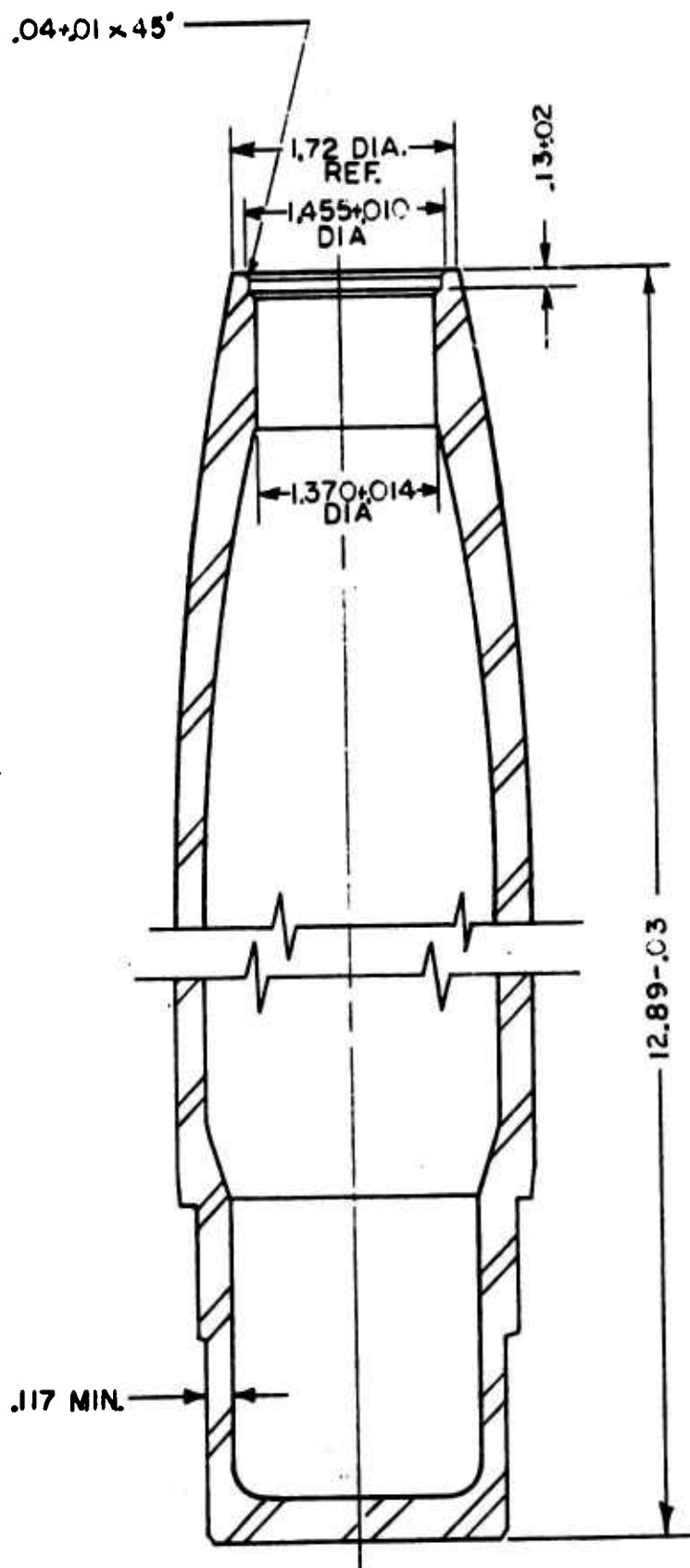
TEMPER

R°C 52-58



OPERATION #150 - FINISH BASE & CHAM. BODY

MACH.: NEW BRITAIN 1867 (U) FIGURE 9(CONTD)

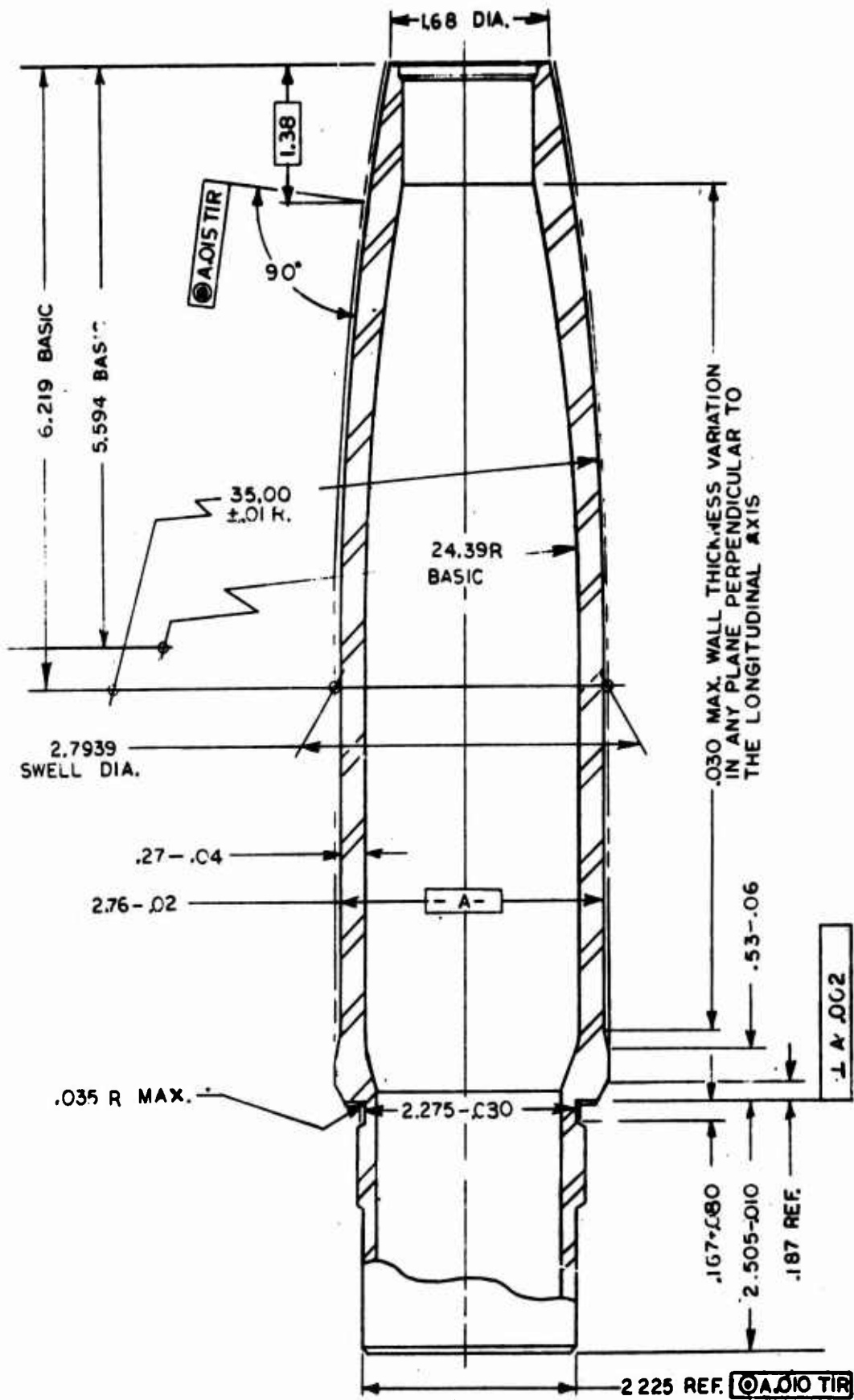


OPERATION #155 - ROUGH NOSE COMPLETE

40

MACH: NEW BRITAIN 2036

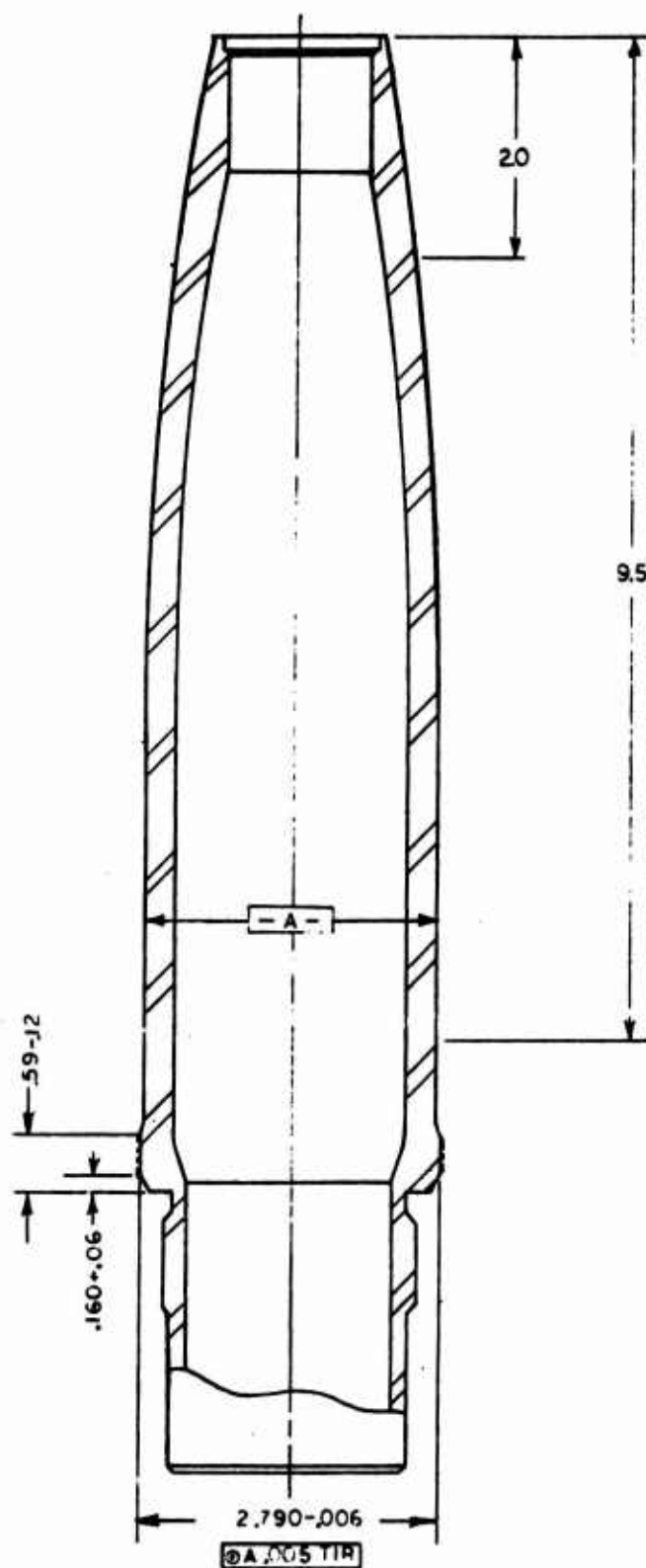
(U) FIGURE 9
(CONTD)



OPERATION 160 - MACH. CONTOUR BODY
AND UNDERCUT

MACHINE: SUNSTRAND 1866 & 1888

(U) FIGURE 9
(CONTD)



OPERATION *162 - MACH. BOURRELET

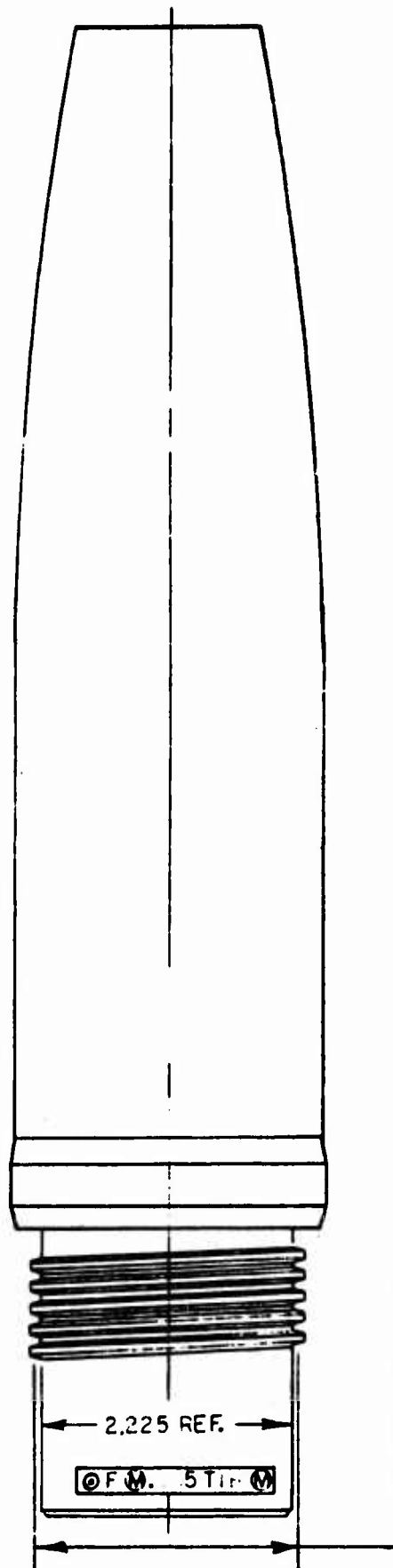
MACHINE: MONARCH 2034

OPERATION *163 - HARDNESS TEST

ROCKWELL C52-59 AT 2 ± 9½ LOCATION FROM NOSE END

42

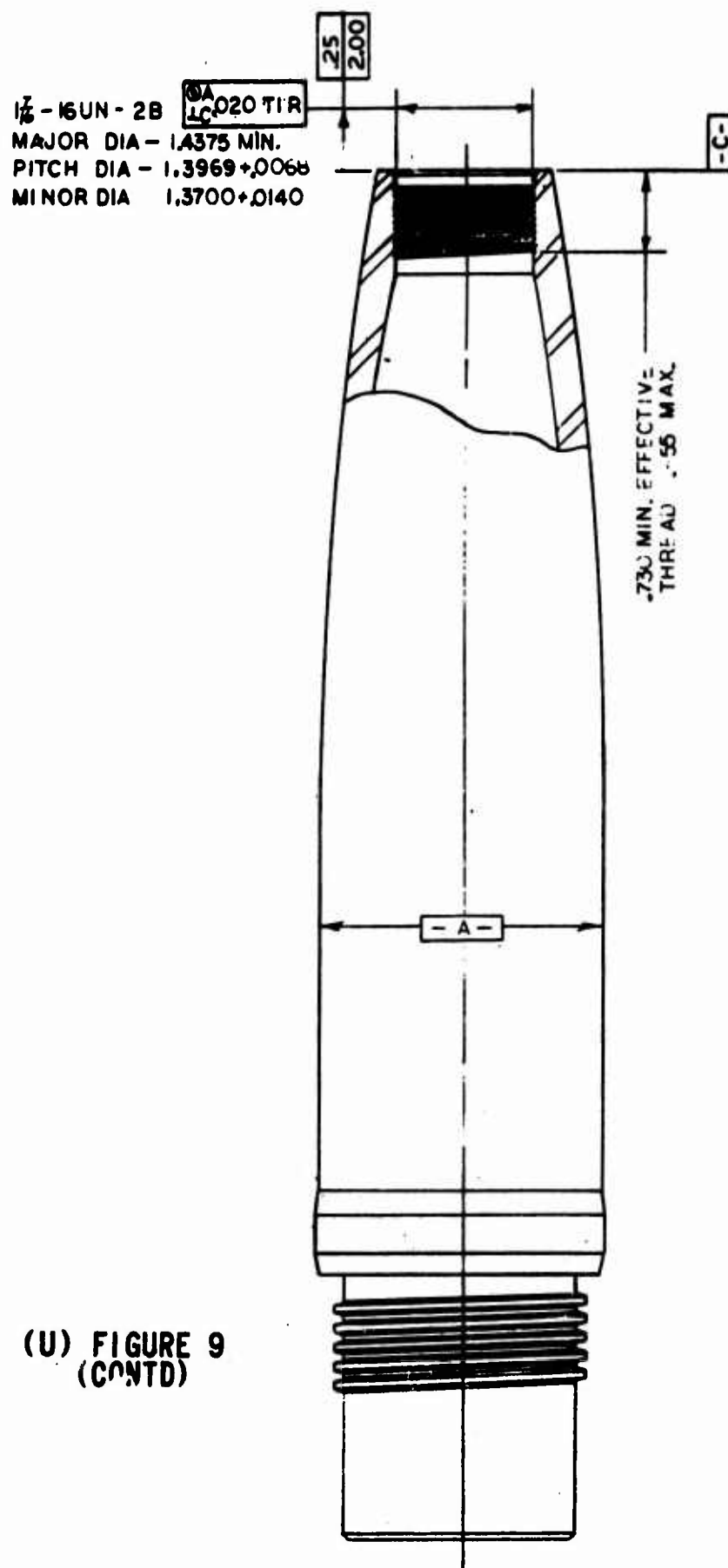
(U) FIGURE 9 (CONTD)



2.4-6-29° STUB ACME-
 3GMCD.
 MAJOR DIA. 2.4000-0.003
 PITCH DIA. 2.3407-0.001 -F-
 MINOR DIA. 2.2800-0.0150 M.S.

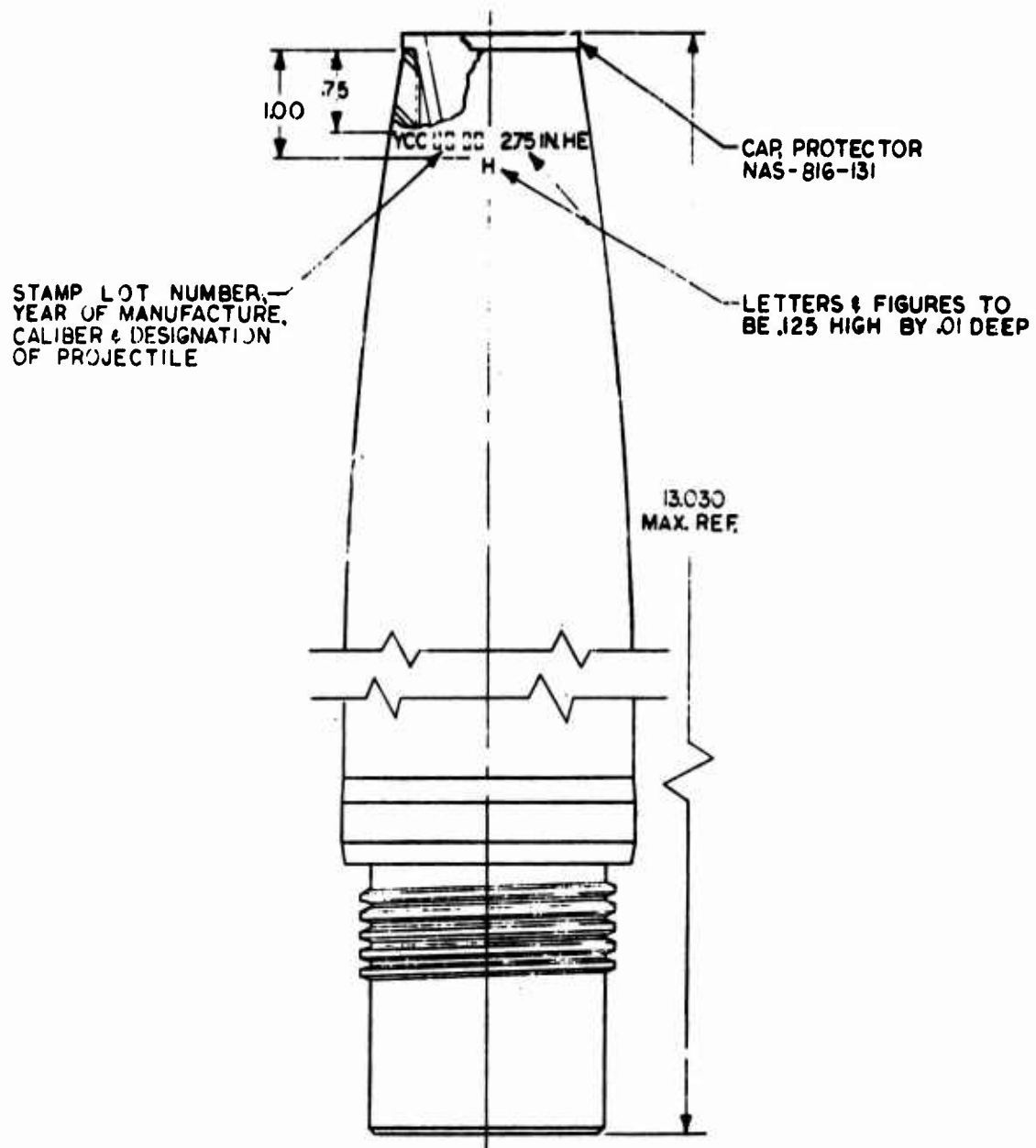
OPERATION #165 MACH. ACME THD.
 MACHINE: CRI-DAN 1874

(U) FIGURE 9
 (CONTD)



(U) FIGURE 9
 (CONTD)

OPERATION #167-MACH. NOSE THD.



<u>OPER. NO.</u>	<u>OPER. DESCRIPTION</u>
170	— FLUSH BEFORE HYDRO TEST
180	— HYDRO TEST (5000 PSI/5 SEC)
181	— STAMP "H" AFTER HYDRO
182	— CLEAN AFTER HYDRO TEST
185	— STAMP NOMENCLATURE
190	— METAL PREP BEFORE PAINT
195	— PAINT
200	— APPLY SILICONE (THREADS)
205	— ASSEMBLE CAP PROTECTOR
210	— PACK

(U) FIGURE 9
(CONTD)

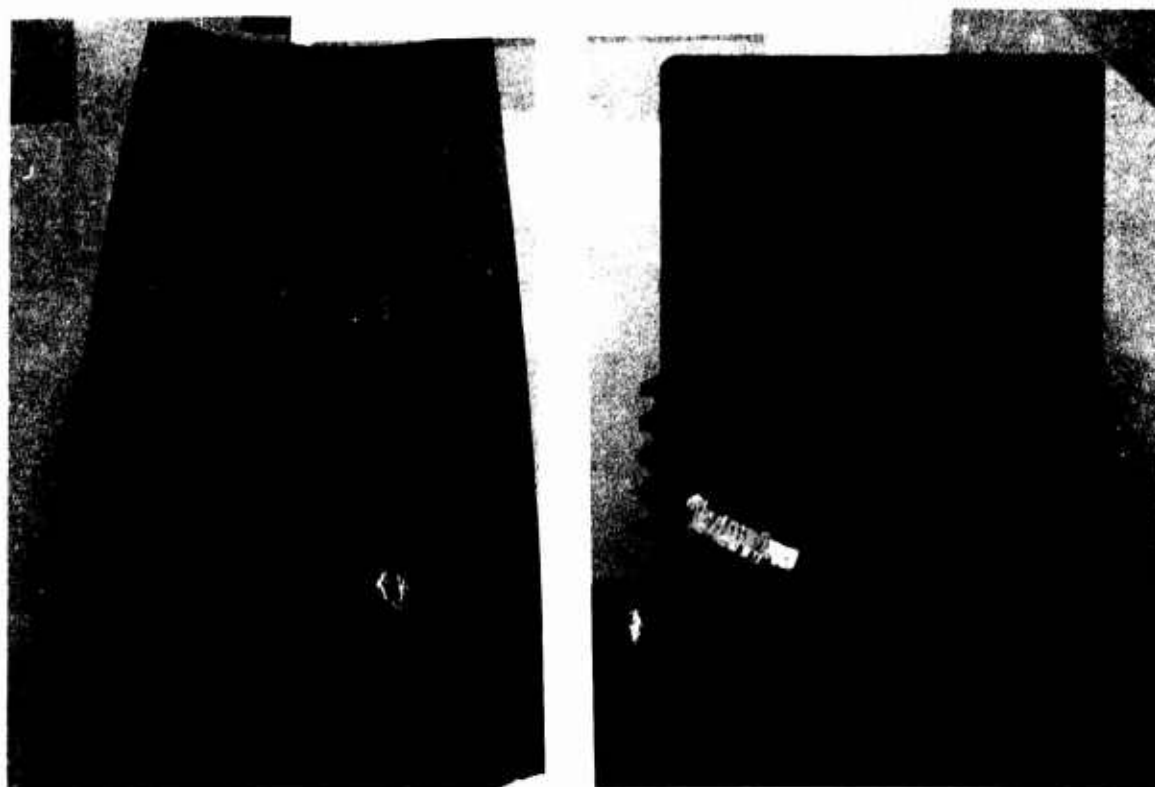
The vertical bars
have "stops" for
controlling the
process



Note the two warheads
simultaneously passing
through the copper coil

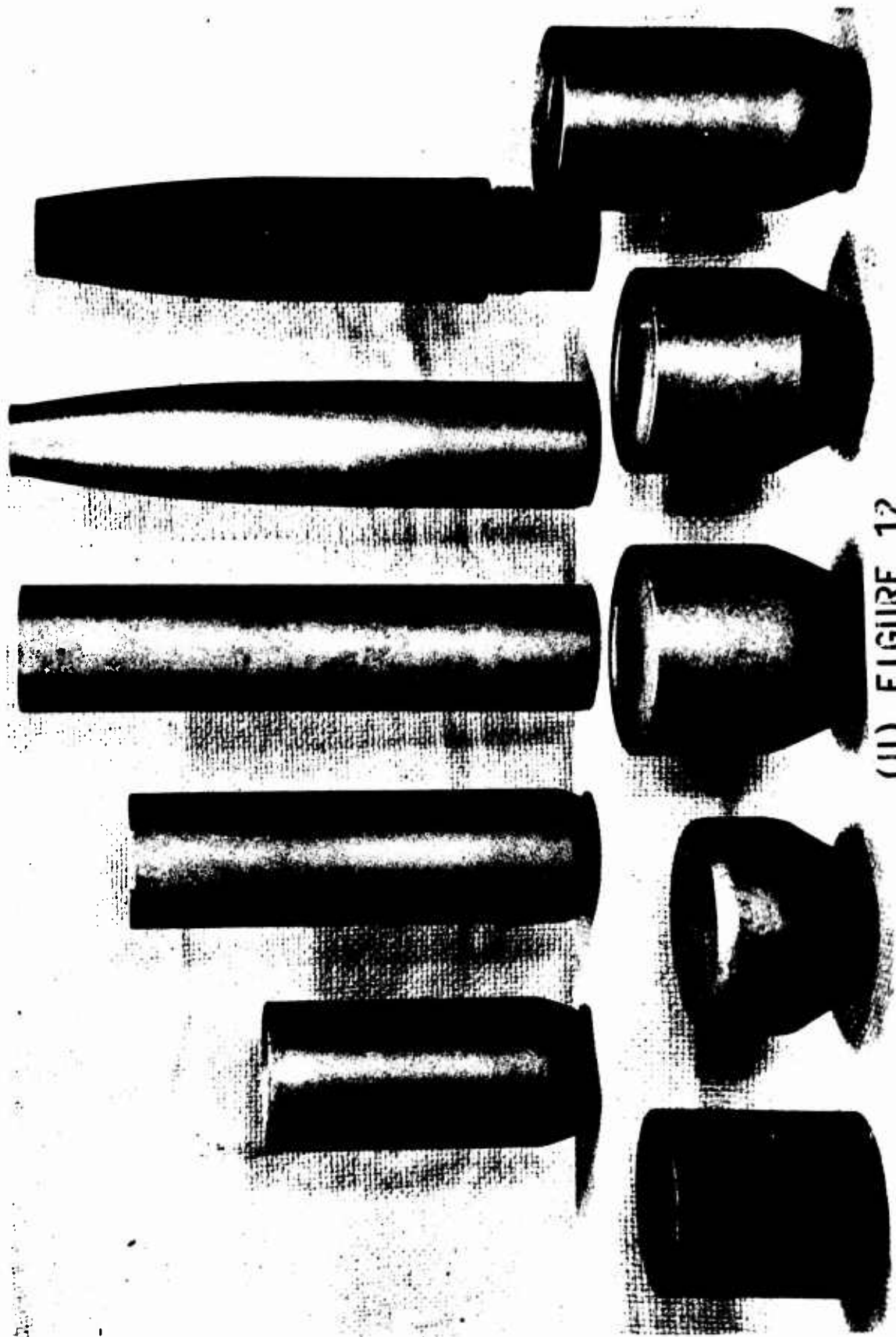


(U) FIGURE 10
INDUCTION SCANNER HEAT TREATMENT UNIT
FOR SELECTIVELY HARDENING 2.75-INCH
WARHEAD METAL PARTS



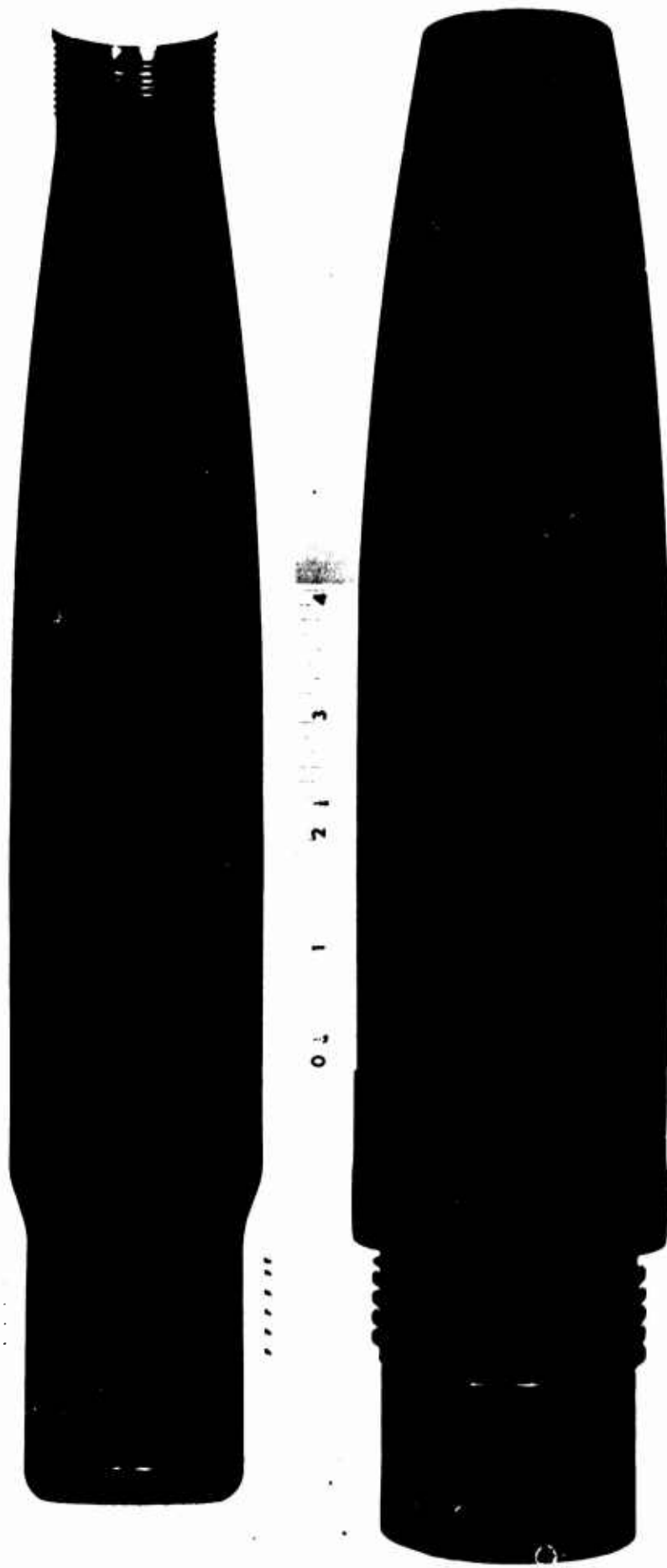
(U) FIGURE 11
THE INDUCTION SCANNER SELECTIVELY
HARDENED WARHEAD LEAVING NOSE AND BASE
AREAS SOFT. NOTE THE DARK HARDENED AREAS

VARIOUS METALWORKING STAGES OF PRODUCTION PROCESS

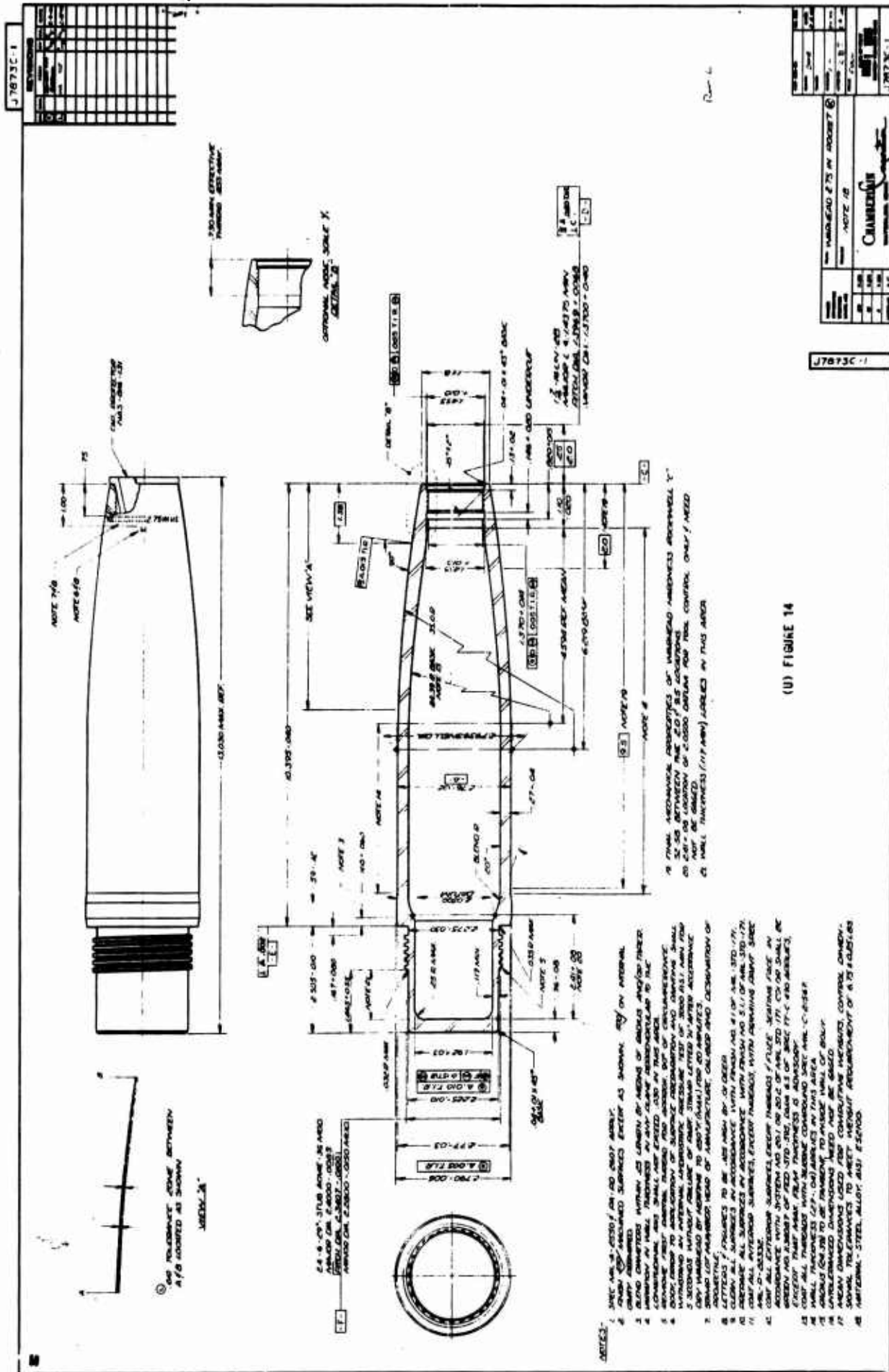


(U) FIGURE 12

FINISH PRODUCTION WARHEAD



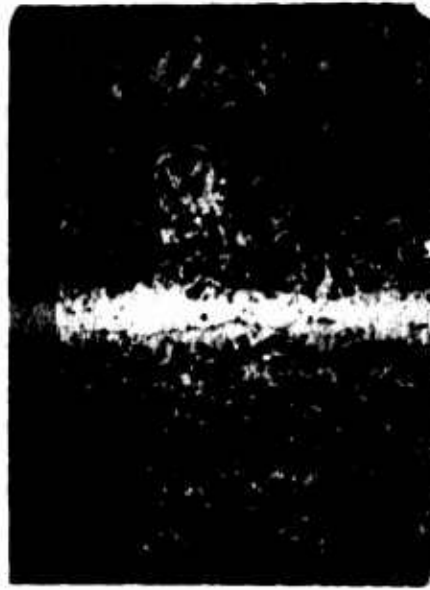
(U) FIGURE 13



(U) FIGURE 14



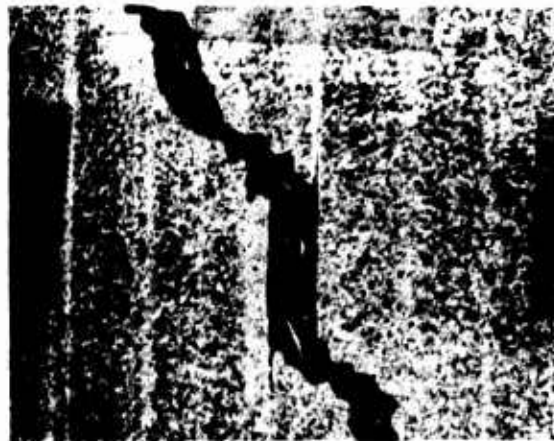
A 50X
Typical transition zone between soft
nose or base and hard center area



B 500X
Severe carbide banding observed
parallel to center line



C Macro
Crack found on inside surface



D 250X
Note how crack propagates through bands

(U) FIGURE 15
METALLURGICAL EVALUATION OF A PRODUCTION
WARHEAD

Height	Number Dropped	Number Cracked	Remarks
40 feet	1	1	All warheads inert loaded. All Warheads inspected using magnetic particle inspection equipment (Maguaglo) before and after tests.
10 feet	3	2	
5 feet	11	5	
4 feet	6	2	
3 feet	3	2	
10 feet	4	4	All warheads were empty. Cracks were inspected visually only.
7 feet	8	7	
6 feet	3	0	
5 feet	9	0	

(U) FIGURE 16
 DROP TESTS FOR 2.75-INCH WARHEADS
 (52100 STEEL). ALL WARHEADS WERE
 DROPPED BARE IN A HORIZONTAL POSITION
 ON A STEEL PLATE

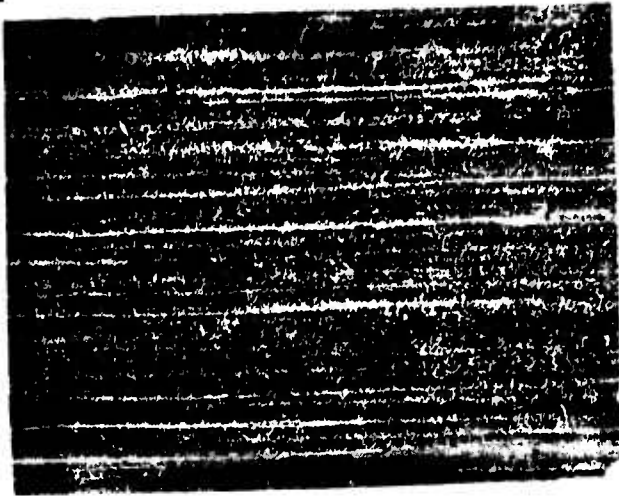


100x

(U) FIGURE 17
PHOTOMICROGRAPH SHOWING CRACK
SURFACE PARALLEL TO BANDING



100x
A



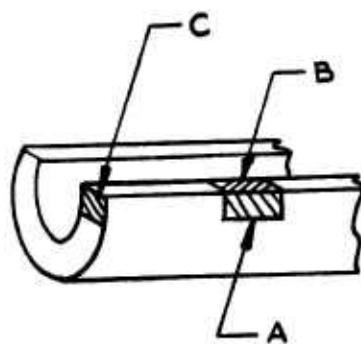
100x

B



100x

C



(U) FIGURE 18
PHOTOMICROGRAPHS OF 52100 STEEL WARHEAD
SHOWING BANDING STRUCTURE IN THREE
GEOMETRIC PLANES



100x

A



100x

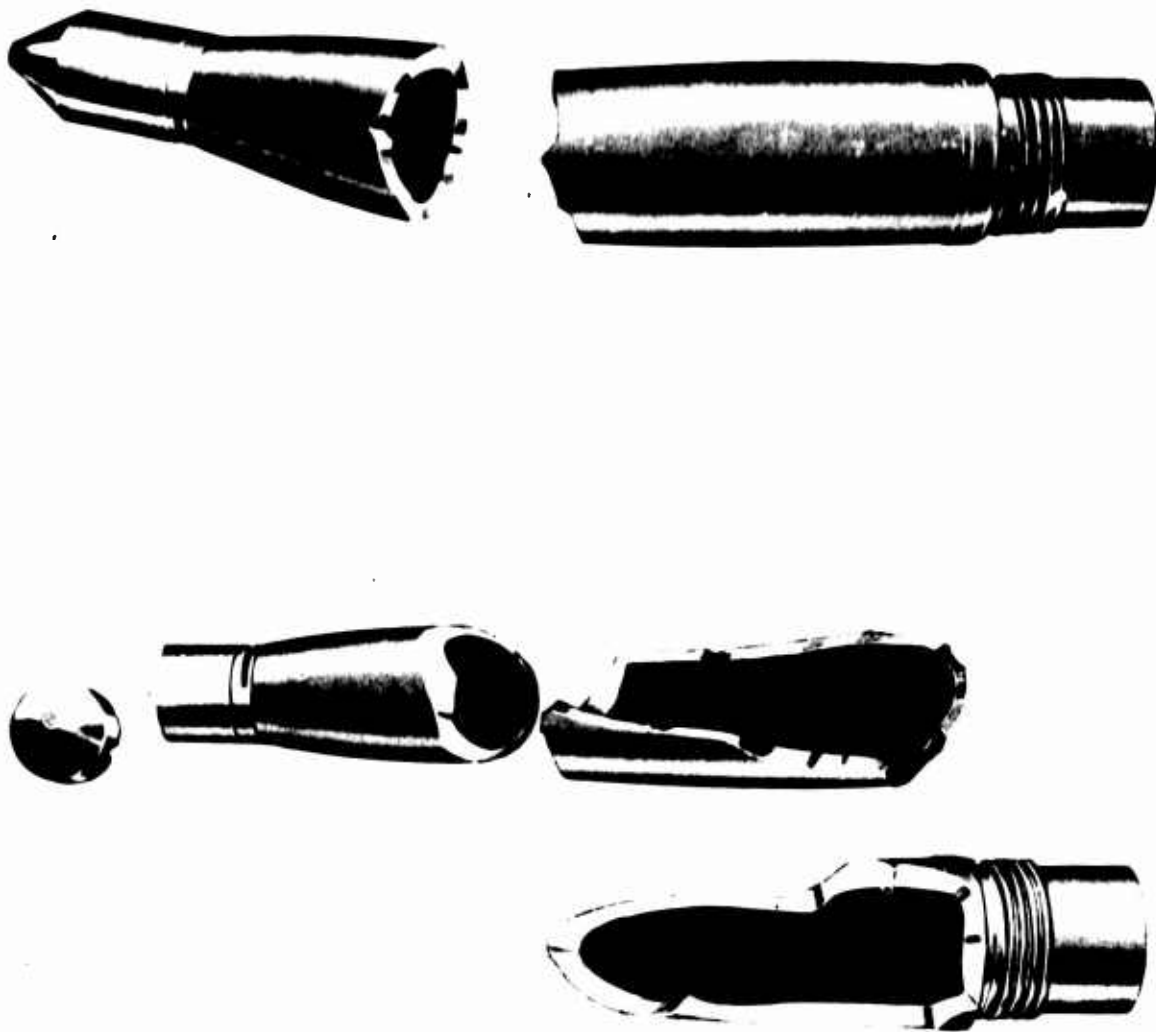
B

(U) FIGURE 19

**MICROGRAPHS OF INITIAL TEST SAMPLES
(A) AND PRESENT PRODUCTION SAMPLES (B).
NOTE BANDING IN PRESENT PRODUCTION ONLY.**



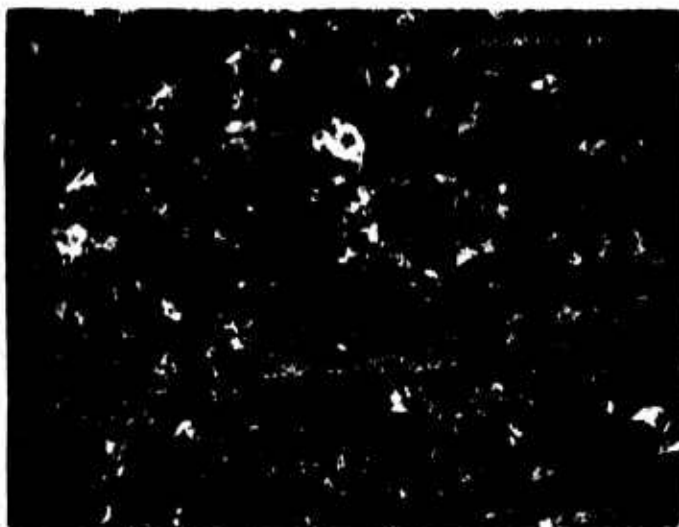
(U) FIGURE 20
PHOTOGRAPHS OF TYPICAL FRACTURE PATTERN
ON PRODUCTION WARHEADS AFTER DROP TESTS ON STEEL PLATE
(CRACKS ARE HIGHLIGHTED)



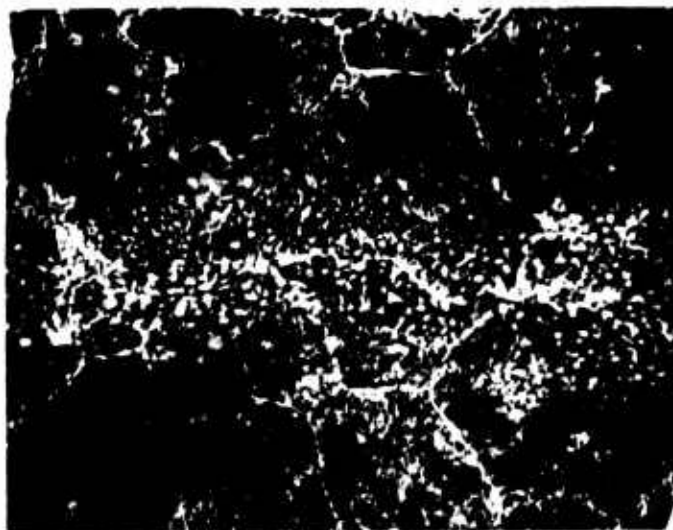
**PHOTOGRAPHS OF TWO BROKEN WARHEADS
DROPPED 40 FEET ON A STEEL PLATE
DURING INITIAL TEST PHASE**

(Reproduced from poor photographs)

FIGURE 21

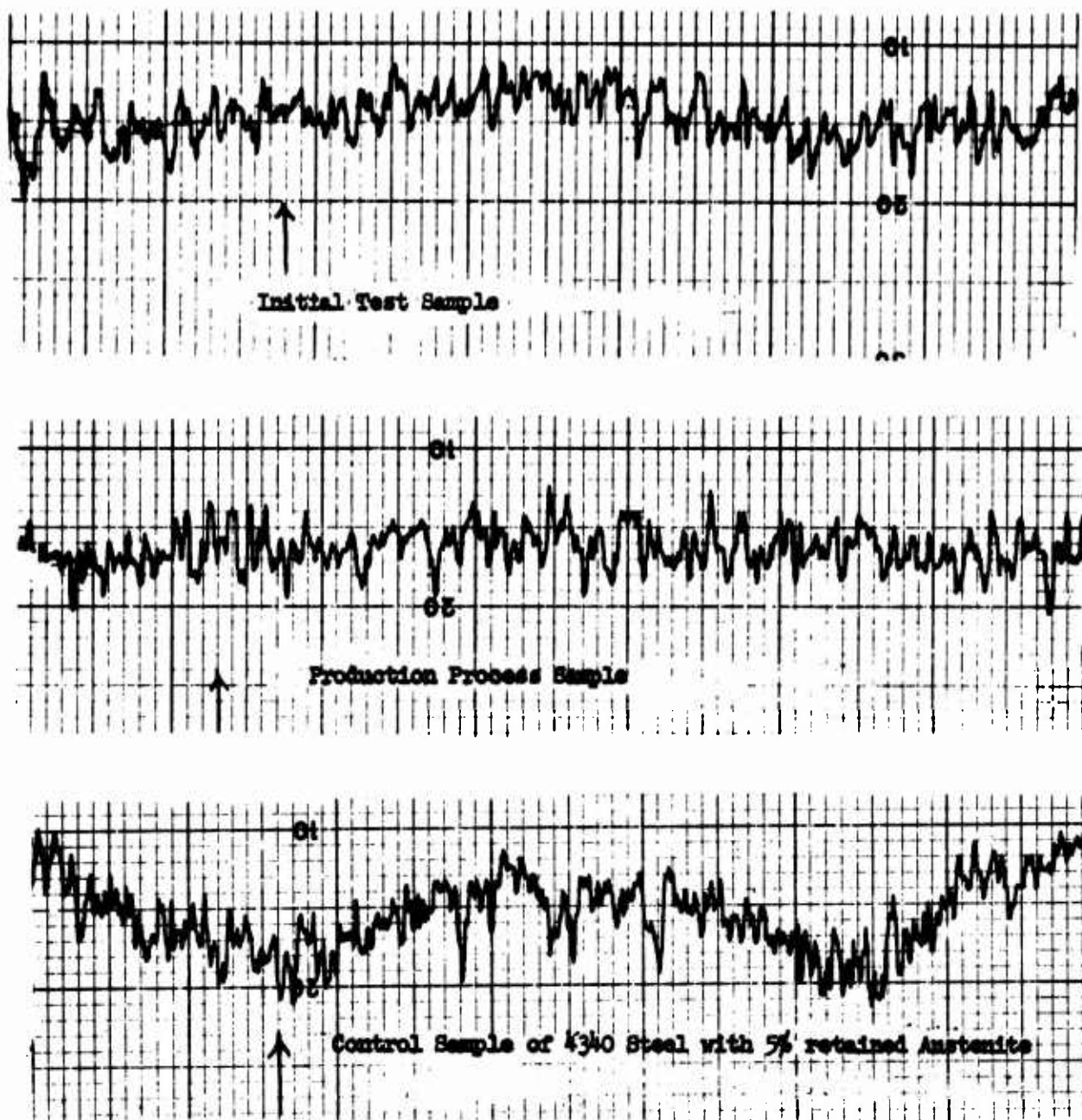


100X

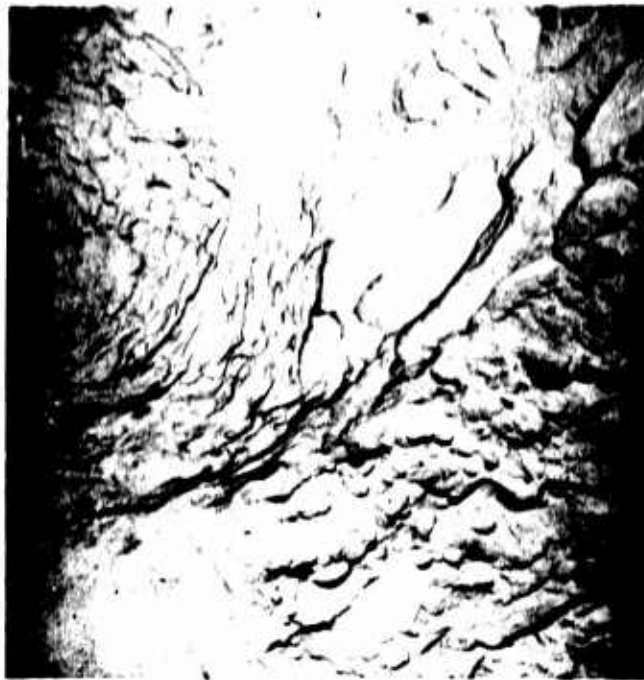


500X

(U) FIGURE 22
MICROGRAPHS OF TYPICAL STARTING SLUG
USED FOR PRODUCTION PROCESS, TAKEN
IN THE DIRECTION OF WORK



(U) FIGURE 23
RETAINED AUSTENITE MEASUREMENTS BY X-RAY
DIFFRACTION. COMPARISON OF INITIAL TEST
SAMPLE WITH PRESENT PRODUCTION SAMPLE
USING A CONTROL SAMPLE CONTAINING ABOUT
5% RETAINED AUSTENITE



Initial Test Sample



Present Production Sample

(U) FIGURE 24
ELECTRON MICROSCOPIC FRACTOGRAPHS OF
INITIAL TEST SAMPLE AND PRESENT
PRODUCTION SAMPLE
(ABOUT 7000X)

SUMMARY OF DROP TEST RESULTS

TEST NUMBER	HEAT TREATMENT	TEMPER	HARDNESS	HEIGHT-WARHEAD* TO STEEL PLATE	NUMBER DROPPED	NUMBER CRACKED**	REMARKS
1	Induction Scanner	650° F	55 - 59 Rc	5	10	5	
2	Induction Scanner	650° F	55 - 59 Rc	10	10	5	
3	Induction Scanner	700° F	52 - 56 Rc	5	10	3	
4	Induction Scanner	700° F	54 - 55 Rc	10	10	3	
5	Induction Scanner	750° F	52 - 53 Rc	5	10	1	
6	Induction Scanner	800° F	50 - 53 Rc	5	10	4	
7	Induction Scanner	800° F	50 - 53 Rc	10	10	1	
8	Induction Scanner	850° F	44 - 50 Rc	5	10	0	ok
9	Induction Scanner	850° F	44 - 50 Rc	10	10	0	ok
10	Induction Scanner	850° F	44 - 49 Rc	5	10	1	
11	Induction Scanner	800° F	49 - 52 Rc	5	21	4	
12	Induction Scanner	700° F	51 - 55 Rc	5	10	2	
13	Induction Scanner	700° F	48 - 51 Rc	5	9	1	
14	1550° F/Furnace, Oil Quench	600° F	54 - 55 Rc	10	6	4	
15	1550° F/Furnace, Oil Quench	700° F	52 - 54 Rc	5	10	2	
16	1550° F/Furnace, Oil Quench	750° F	48 - 51 Rc	5	10	0	
17	1550° F/Furnace, Oil Quench	750° F	48 - 51 Rc	10	10	1	
18	1550° F/Furnace, Oil Quench	800° F	49 - 51 Rc	5	10	0	ok
19	1550° F/Furnace, Oil Quench	800° F	49 - 52 Rc	10	10	0	ok
20	1450° F/Furnace, Oil Quench	700° F	42 - 48 Rc	5	9	1	
21	Normalized 1550° F, Induction Scanner	700° F	49 - 57 Rc	5	10	0	
22	Normalized 1550° F, Induction Scanner	700° F	49 - 57 Rc	10	10	7	
23	Normalized 1750° F, Induction Scanner	700° F	49 - 56 Rc	5	12	7	
24	Normalized 1750° F, Induction Scanner	800° F	45 - 51 Rc	5	8	3	
25	Normalized 1750° F, Induction Scanner	900° F	42 - 47 Rc	5	9	3	
26	Normalized 1650° F	-----	23 - 29 Rc	5	12	0	ok
27	Normalized 1650° F	-----	23 - 29 Rc	10	12	0	ok
28	Normalized 1750° F TTT	-----	91-95 Rc (O.D.)	5	10	0	Soft O.D. due to decarburization
29	Normalized 1750° F TTT	-----	35 Rc (I.D.)	10	10	0	
30	Normalized 1750° F	-----	28 - 35 Rc	5	10	2	
31	1560° F, 2 Min Delay, Oil Quench	-----	23 - 37 Rc	5	5	0	Frag not good
32	1560° F, 2 Min Delay, Oil Quench	-----	23 - 37 Rc	5	5	0	wide hardness range
33	1550° F Salt Bath	-----	23 - 37 Rc	10	5	0	

FOOT NOTES:

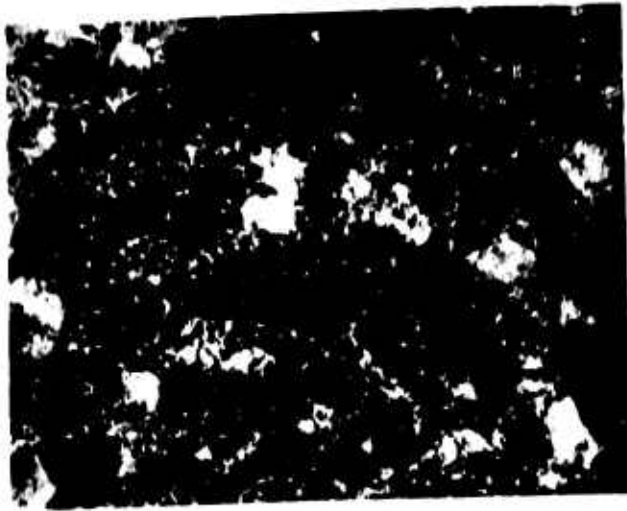
*All warheads dropped in a horizontal position on a flat steel plate.

**All warheads inspected by "Magnaflux" before and after drop tests.

T - Delays up to 12 hours were incurred between scanner H.T. and tempering treatment. This reflected actual production delays and may have contributed to poor drop test results.

TT - Immediate tempering performed to determine if shorter time results in successful drop tests.

TTT - Normalized after final O.D. contour machining.



500X

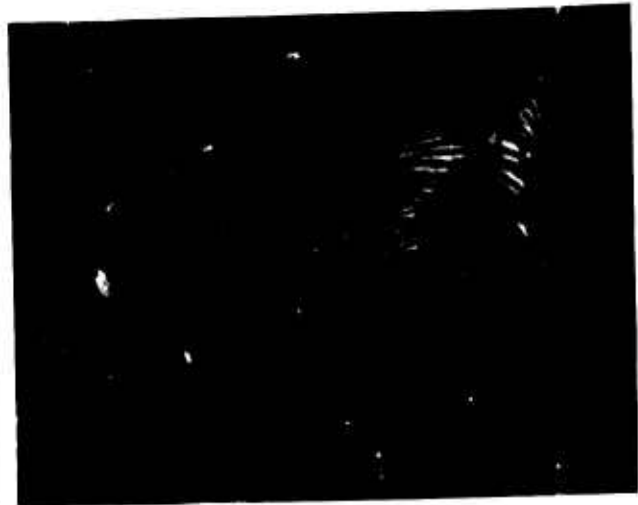


250X

Normalized, 1650°F Air Cooled



Normalized, then Machined



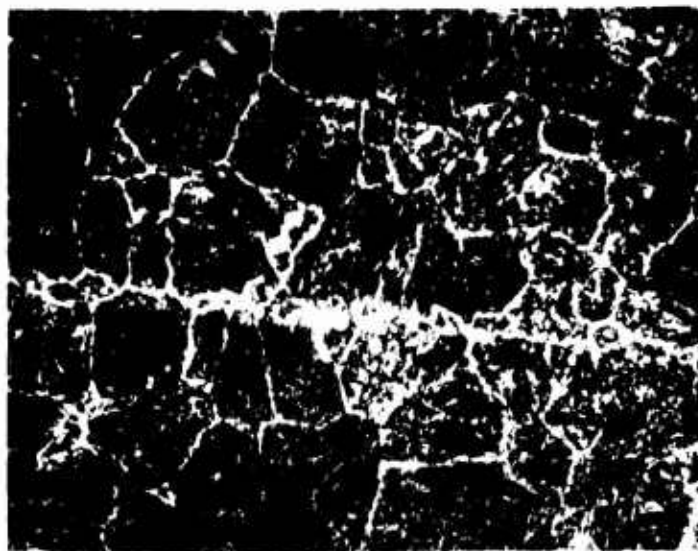
Normalized after Machining

Normalized, 1750°F Air Cooled, 500X

FIGURE 26 PHOTOMICROGRAPHS OF NORMALIZING HEAT TREATMENTS FOR 52100 STEEL WARHEADS



500X



250X

FIGURE 27
PHOTOMICROGRAPHS OF 52100 STEEL
WARHEADS SUBJECTED TO A
CARBIDE NETWORK HEAT TREATMENT

TESTS

Samples	Tensile Strength psi	Yield Strength psi	% Elong.	Charpy++ ft.-lb. Avg.
Initial Test Samples (contract 2230) R _c 55-56**	299,000 299,400 299,200 Avg	264,000 264,000 264,000 Avg	3.2 2.4 2.8 Avg	1.72 1.44 1.80 1.65 Avg
Production Samples (Contract 2354) R _c 55-58**	+	282,000 281,000 281,000 Min	+	0.80 0.95 0.38 0.71 Avg
Production Samples Modified R _c 44-46**	215,384 216,867 216,125 Avg	212,637 207,229 209,933 Avg	10%	4 4 Avg
Production Sample Modified R _c 49-50**	248,913 246,875 247,894 Avg	233,696 234,375 234,035 Avg	7.5 5.0 6.7 Avg	3.5 3.5 Avg
Normalized 1650°F R _c 23-29**	170,000 160,500 165,250 Avg	85,000 67,000 76,000 Avg	11 11 11	1.20 1.36 1.00 1.19 Avg
Carbide Network Heat Treatment	177,000 176,000 176,500 Avg	130,000 128,000 129,000 Avg	*	2.72 2.68 2.70 Avg

+Two samples broke in threaded area. No tensile or elongation data was obtained. However, psi reduced 282,500 and 281,000.

++One-Third (1/3) Standard Size Charpy Specimens

*Broke outside gage length.

**Rockwell C Scale

FIGURE 28 SUMMARY OF PHYSICAL PROPERTIES FOR VARIOUS HEAT TREATMENTS OF 52100 STEEL 2.75-INCH WARHEAD M/PTS

APPENDIX B

Tables

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TABLE 1

CYLINDER TEST RESULTS

Weight Percent Fragments vs. Fragment Weight Groups (Grains)

Fragmentation Weight Groups (Grains)	Sample Number					
	900°F Temper R _C 44-45	800°F Temper R _C 45-47	700°F Temper R _C 47-69	600°F Temper R _C 50-52	500°F Temper R _C 54-56	400°F Temper R _C 57-58
0.0-0.5	2.1	2.5	3.3	5.5	7.1	8.4
0.5-2.0	7.1	14.4	18.7	25.7	32.4	35.9
2.0-5.0	18.4	25.2	32.2	30.7	37.5	38.7
5.0-10.0	22.0	27.7	23.6	24.0	17.0	14.9
10.0-20.0	24.1	18.0	17.2	12.0	6.0	2.1
20.0-25.0	4.4	4.5	1.1	2.1	0	0
25.0-50.0	19.2	5.0	3.9	0	0	0
50.0-75.0	2.7	2.7	0	0	0	0

The Cylinders represent the following parameters:

Material: E52100 Steel

Dimensions: 2.75 inch 0.0 x 2.75 inch 1.0 x 4 inch long

Heat Treat: 1550°F, Oil Quench (Tempered as noted above).

CONFIDENTIAL

CONFIDENTIAL

TABLE 2

TOTAL NUMBER FRAGMENTS VS. FRAGMENT WEIGHT GROUPS (GRAINS)

Fragment Weight Groups (Grains)	Sample Numbers													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.0-0.5	56	231	687	355	---	---	915	755	600	710	---	---	---	---
0.5-0.8	1545	1997	2817	2587	1986	2774	1308	1298	617	1202	1259	1264	912	1378
0.8-2.0	3699	3414	5548	5292	5764	5683	2492	2416	1314	2942	2733	2946	2099	2234
2.0-3.0	1320	1304	2053	1942	1919	2153	905	958	531	1040	968	1071	795	850
3.0-5.0	1248	1420	1984	1876	1728	1948	993	1046	561	1240	1119	1157	831	977
5.0-7.0	728	743	876	911	747	888	585	551	351	668	610	610	509	546
7.0-10.0	579	621	543	583	597	563	528	536	280	585	591	560	464	505
10.0-15.0	452	481	272	315	367	374	512	453	255	495	477	555	411	393
15.0-20.0	254	218	87	90	135	125	258	273	206	252	270	272	242	222
20.0-30.0	175	130	79	56	69	69	266	275	217	255	229	233	224	236
30.0-50.0	62	78	28	33	49	24	179	170	199	118	151	118	179	182
50.0-75.0	15	24	16	16	23	8	47	46	132	31	39	30	79	61
75.0-150.0	12	13	25	24	21	11	26	25	84	14	10	13	29	30
150.0-750.0	7	7	9	8	10	3	10	6	17	12	1	2	2	3
750.0-5000.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	10,152	10,681	15,024	14,088	13,415	14,623	9,024	8,802	5,364	5,564	8,457	8,833	6,776	7,619

Legend

- 1 PMI Warheads
2 Warheads f/initial test program
3 Contract 2230
4 Contract 2230
5 Production Warheads
6 Scan H.T. R_c 56-58, Contract 2354
7 Modified Production w/hds
8 R_c 44-46
9 Modified Production w/hds
10 R_c 49-50
11 Normalized 1650°F
12 R_c 23-29
13 Carbide Network H.T.
14 R_c 35-38

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CONFIDENTIAL

TABLE 3

TOTAL WEIGHT FRAGMENTS (OUNCES) VS. FRAGMENT WEIGHT GROUPS (GRAINS)

Fragment Weight Groups (Grains)	Sample Numbers													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.0-0.5	0.056	0.229	0.705	0.374	-----	-----	0.680	0.518	0.423	0.547	-----	-----	-----	-----
0.5-0.8	2.371	3.028	4.237	3.925	3.115	4.155	1.970	1.915	0.918	1.803	1.941	1.952	1.411	2.128
0.8-2.0	11.047	10.311	16.612	16.037	17.099	17.143	7.560	7.390	3.992	8.786	8.143	8.867	6.251	6.649
2.0-3.0	7.381	7.376	11.592	10.945	10.792	12.146	5.123	5.426	2.902	5.878	5.467	6.058	4.519	4.831
3.0-5.0	11.050	12.571	17.324	16.523	15.250	17.099	8.783	9.295	5.013	11.025	10.029	10.229	7.371	8.742
5.0-7.0	9.901	10.075	11.753	12.290	9.972	11.933	7.914	7.438	4.817	9.061	8.278	8.265	6.922	7.433
7.0-10.0	11.089	11.926	10.265	10.984	11.279	10.726	10.096	10.194	5.384	11.177	11.322	10.693	8.921	9.657
10.0-15.0	12.517	13.291	7.502	8.585	9.949	10.264	14.186	12.651	7.111	13.880	13.359	15.565	11.451	10.957
15.0-20.0	10.015	8.529	3.383	3.481	5.296	4.902	10.221	10.773	8.137	9.950	10.655	10.732	9.620	8.755
20.0-30.0	9.673	7.067	4.302	3.051	3.837	3.711	14.834	15.504	12.015	14.131	12.697	12.750	12.396	13.201
30.0-50.0	5.001	6.688	2.395	2.934	4.202	2.077	15.291	14.879	17.555	9.941	13.038	9.962	15.533	15.925
50.0-75.0	2.223	3.345	2.150	2.246	3.170	1.217	6.454	6.265	18.116	4.300	5.458	3.998	10.586	8.263
75.0-150.0	2.622	3.049	6.192	5.821	5.162	2.806	5.744	6.102	19.701	3.555	2.390	3.171	6.522	6.326
150.0-750.0	4.806	4.025	3.907	4.338	4.460	1.686	5.013	3.741	7.534	5.353	0.759	1.154	1.175	1.623
750.0-500.0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.292
Total	6 lbs 3.752oz	6 lbs 5.507oz	6 lbs 6.321oz	6 lbs 5.534oz	6 lbs 7.582oz	6 lbs 3.866oz	7 lbs 1.870oz	7 lbs 0.091oz	7 lbs 1.698oz	6 lbs 13.389oz	6 lbs 7.537oz	6 lbs 7.395oz	6 lbs 6.668oz	6 lbs 13.780oz

Legend is the same as Table 2.

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TABLE 4

WEIGHT PERCENT FRAGMENTS VS. FRAGMENT WEIGHT GROUPS (GRAINS)

Fragment Weight Groups (Grains)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.0-0.5	2.38	2.99	4.17	3.88	3.01	4.16	1.74	1.72	0.81	1.66	1.87	1.89	1.37	1.94
0.5-0.8	11.08	10.18	16.35	15.85	16.51	17.17	6.68	6.62	3.52	8.07	7.8	8.58	6.09	6.06
0.8-2.0	7.40	7.28	11.41	10.82	10.42	12.16	4.53	4.86	2.63	5.40	5	5.86	4.40	4.40
2.0-3.0	11.08	12.41	17.05	16.33	14.72	17.12	7.76	8.33	4.43	10.13	9.5	9.89	7.18	7.96
3.0-5.0	9.93	9.95	11.57	12.15	9.63	11.95	6.99	6.67	4.25	8.32	8.00	7.99	6.74	6.77
5.0-7.0	11.12	11.78	10.10	10.86	10.89	10.74	8.92	9.14	4.75	10.27	10.93	10.34	8.69	8.80
7.0-10.0	12.55	13.12	7.38	8.49	9.60	10.28	12.53	11.34	6.28	12.75	12.90	15.05	11.15	9.98
10.0-15.0	10.05	8.42	3.33	3.44	5.11	4.91	9.03	9.66	7.18	9.14	10.29	10.38	9.37	7.97
15.0-20.0	9.70	6.98	4.23	3.02	3.70	3.72	13.11	13.90	10.61	12.98	12.26	12.33	12.07	12.02
20.0-30.0	5.02	6.60	2.36	2.90	4.06	2.08	13.51	13.34	15.50	9.13	12.59	9.63	15.13	14.51
30.0-50.0	2.23	3.30	2.12	2.22	3.06	1.22	5.70	5.62	15.99	3.95	5.27	3.87	10.30	7.53
50.0-75.0	2.63	3.01	6.09	5.75	4.98	2.81	5.07	5.47	17.39	3.27	2.31	3.07	6.35	5.76
75.0-150.0	4.82	3.97	3.85	4.29	4.31	1.69	4.43	5.35	6.65	4.92	0.73	1.12	1.14	1.48
150.0-750.0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.82
750.0-500.0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.82

Legend is the same as Table 2.

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TABLE 5
LETHAL AREA RATIOS
OF
PMI VS. 52100 STEEL 2.75 WARHEADS

Prone men (one point target)

Type	2°	5°	10°	15°	20°	30°	40°
PMI	1.00	1.00	1.00	1.00	1.00	1.00	1.00
52100 Steel	1.08	1.08	1.10	1.08	1.07	1.09	1.06

Standing Men

Type	2°	5°	10°	15°	20°	30°	40°
PMI	1.00	1.00	1.00	1.00	1.00	1.00	1.00
52100 Steel	1.06	1.05	1.07	1.08	1.07	1.05	1.04

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ROCKET WARHEAD (U)

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13. ABSTRACT

(U) Hypereutectoid Type A151 E52100 steel was evaluated by the
Ammunition Engineering Directorate's Ammunition Engineering
Laboratory for its suitability as an alternate material for the two-
piece pearlitic malleable iron XM151 Warhead of the 2.75-Inch
Rocket System.

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